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Empennage Design with Single and Multiple Vertical Surfaces

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SUMMARY

Wind-tunnel tests on models with flaps up have been analyzed to obtain surface and control efficiencies for empennages with single and double vertical surfaces. On the basis of these efficiencies and constant static longitudinal stability with (1) constant static directional stability, or (2) constant rudder control, required areas for the DC-4 are compared for empennages with single and double vertical surfaces. Hinge moments for single and double rudders giving constant control are compared; and methods of hinge moment reduction are briefly discussed. The variation of ground clearance is shown with single, double, or triple vertical surfaces. Aerodynamic effects of such design variations as horizontal surface tips, rudder cutouts, vertical location of double vertical surfaces, and horizontal surface dihedral angle are mentioned.

Choice of vertical surface type for a particular design is governed by the fact that (1) for constant rudder control, the single vertical surface gives a relatively high value of static directional stability; double vertical surfaces, a relatively low value; and triple vertical surfaces, an intermediate value with minimum overall airplane height, and that (2) for constant rudder control, the total empennage area with single or double vertical surfaces is approximately equal for all aspect ratios; for constant static directional stability, the total area is less with the single vertical surface.

INTRODUCTION

SPECIFICATION of desired flying qualities prior to design and cost of possible revisions after flight test are factors which have increased the necessity for intelligent empennage design. Operating safety of multi-engine aircraft requires the capability of flight after engine failure, thus requiring as a minimum, adequate rudder for balance of asymmetrical thrust. If the above design condition is satisfied and normal proportions are maintained between fixed and movable vertical surfaces, the static directional stability will, in all probability, be adequate, and the normal tendency will be away from the region of Dutch Roll instability, toward that of spiral instability.

In the design of any large transport airplane another major problem requires adequate solution. A relatively large center of gravity is required if there is to be the desired flexibility in the seating arrangements for a large number of passengers. Since static and dynamic longitudinal stability characteristics of the airplane determine the limiting aft position of the center of gravity, and elevator effectiveness determines the maximum forward position, intelligent design of the fixed and movable horizontal surfaces is essential. A further consideration of empennage design is involved by possible limitation of overall airplane height for hangar clearance. Assuming adequate rudder control, this requirement necessitates the use of multiple vertical surfaces, presenting simultaneously the problem of ground clearance at maximum lift attitude.

Certain important phases of empennage design and the relative merits of empennage designs with single or double vertical surfaces for directional stability and control, and the effect of horizontal surface endplates on the longitudinal stability, will be discussed.

The various surface and control efficiency points were

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obtained from analysis of tests in the 10 ft. Wind Tunnel at the Guggenheim Aeronautics Laboratory, California Institute of Technology, at a wing Reynolds Number of approximately 1,500,000 on numerous Douglas, Lockheed, and miscellaneous models. The empennage arrangements were, in general, similar to those shown in Fig. 1, representing types of efficient aerodynamic form.

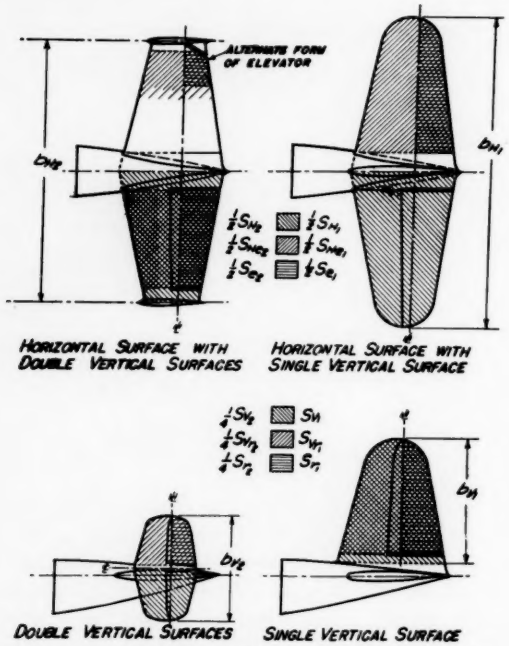
ALTERNATE FORM OF ELEVATOR
HORIZONTAL SURFACE WITH DOUBLE VERTICAL SURFACES
HORIZONTAL SURFACE WITH SINGLE VERTICAL SURFACE
DOUBLE VERTICAL SURFACES
SINGLE VERTICAL SURFACE

FIG. 1. Area definition for horizontal and vertical surfaces.

NOTATION

In addition to the standard N.A.C.A. aerodynamic symbols, the following notation is used in the text:

S_H, S_V = Horizontal or vertical surface area in sq.ft.

S_{H_e}, S_{V_r} = Horizontal or vertical surface area affected by the elevator or rudder in sq.ft.

S_e, S_r = Elevator or rudder area aft of hinge line in sq.ft.

b_H, b_V = Horizontal or vertical surface span in ft.

t = Mean aerodynamic chord of wing in ft.

t_r = Mean chord of rudder aft of hinge line in ft.

l_H, l_V = Distance from center of gravity of airplane to elevator or rudder hinge line in ft.

$A.R._W$ = b^2/S_W = Aspect ratio of wing.

$A.R._H$ = $b_H{}^2/S_H$ = Aspect ratio of horizontal surface.

$A.R._{H_e}$ = Effective aspect ratio of horizontal surface with double vertical surfaces, using η_{H_1}.

$A.R._V$ = $b_V{}^2/S_V$ = Aspect ratio of vertical surface.

H_m = Control surface hinge moment in ft.lb.

C_{m_H} = Pitching moment coefficient about center of gravity due to horizontal surfaces.

C_{n_V} = Yawing moment coefficient about center of gravity due to vertical surfaces.

$a_0 = 2\pi\eta$ = slope of lift curve for infinite aspect ratio, radian measure. (In text, $\eta = 0.875$.)

$dC_L/d\alpha = a_0/(1 + a_0/\pi A.R.)$ = slope of lift curve for finite aspect ratio, radian measure.

$\lambda_e = \partial\alpha_H/\partial\delta_e = fn(S_e/S_{H_e})$ (Fig. 11, reference 1).

$\lambda_r = \partial\psi/\partial\delta_r = fn(S_r/S_{V_r})$ (Fig. 11, reference 1).

η_H = Horizontal surface efficiency.

η_V = Vertical surface efficiency.

η_e = Elevator efficiency.

η_r = Rudder efficiency.

γ = Horizontal surface dihedral angle in degrees.

Subscripts $(\,)_1$, $(\,)_2$ on any of the above symbols indicate whether with single or double vertical surfaces. For example, $A.R._{H_2}$ represents the aspect ratio of a horizontal surface with double vertical surfaces as endplates.

STABILITY AND CONTROL EQUATIONS

The efficiencies of the horizontal surface, vertical surface, elevator, and rudder, respectively, are defined by the following equations:

$$\frac{dC_{m_H}}{dC_L} = -\eta_H \frac{l_H}{t}\frac{S_H}{S_W}\frac{1 - a_0/\pi A.R._W}{1 + a_0/\pi A.R._H} \tag{1}$$

$$\frac{dC_{n_V}}{d\psi} = -\eta_V \frac{l_V}{b}\frac{S_V}{S_W}\frac{a_0}{1 + a_0/\pi\, A.R._V}\frac{\pi}{180} \tag{2}$$

$$\frac{dC_m}{d\delta_e} = -\eta_e \frac{l_H}{t}\frac{S_{H_e}}{S_W}\frac{a_0}{1 + a_0/\pi A.R._H}\frac{\pi}{180}\lambda_e \tag{3}$$

$$\frac{dC_n}{d\delta_r} = -\eta_r \frac{l_V}{b}\frac{S_{V_r}}{S_W}\frac{a_0}{1 + a_0/\pi\, A.R._V}\frac{\pi}{180}\lambda_r \tag{4}$$

The span and area definitions for horizontal and vertical surfaces are given in Fig. 1. In all the above equations, the geometric aspect ratios are used. In the derivation of the equation defining the horizontal surface efficiency, the assumptions are made that the lift distribution over the wing is elliptical, and that the downwash at the horizontal surface due to the wing is twice that at the wing.[2]

ANALYSIS OF EMPIRICAL DATA

From the wind-tunnel tests analyzed, a considerable quantity of data has been collected on surface and control efficiencies.

Horizontal Surface Efficiency

The data presented in Fig. 2 consist of horizontal surface efficiencies for empennages with single vertical surfaces. These results have been restricted to empennage types for which the vertical surfaces were directly over the horizontal surfaces as shown in Fig. 1. Fig. 3

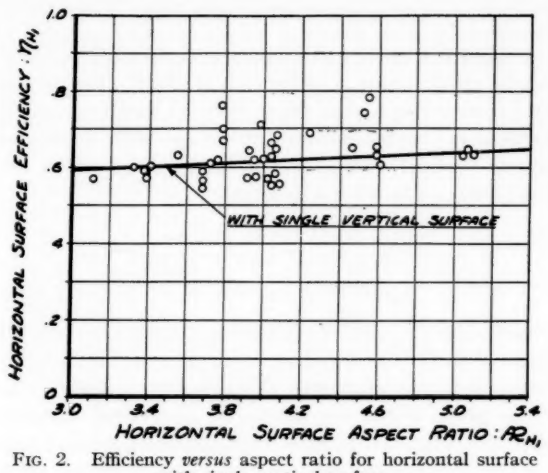

FIG. 2. Efficiency *versus* aspect ratio for horizontal surface with single vertical surface.

gives the efficiency ratio for horizontal surfaces with and without double vertical surfaces of various span ratios. To obtain the horizontal surface efficiency η_{H_2}, care must be taken to obtain η_{H_1} from Fig. 2 for the geometric aspect ratio which is to be used for double vertical surface empennage. For design use, Fig. 4, a combination of Figs. 2 and 3, has been prepared from which η_{H_2} may be obtained directly. It is noted that for a span ratio of 0.5 and for the same horizontal surface aspect ratio an empennage with endplates will give approximately a 22 percent increase in longitudinal stability due to horizontal surfaces only.

Vertical Surface Efficiency

The efficiencies of single and double vertical surfaces are plotted in Fig. 5. Since it has been customary

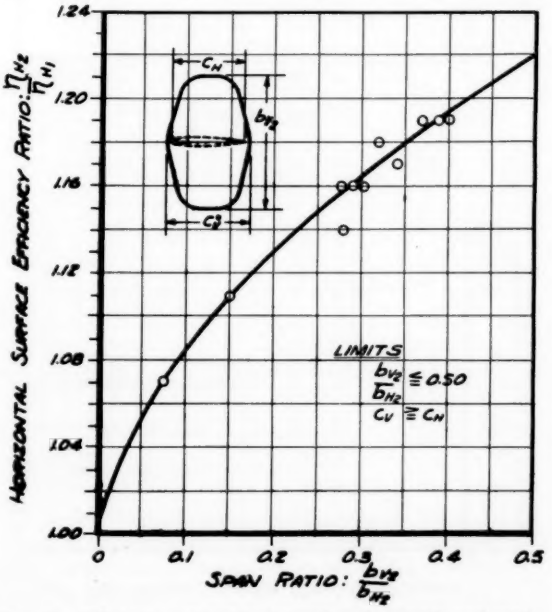

FIG. 3. Efficiency ratio of horizontal surface with and without double vertical surfaces, *versus* span ratio.

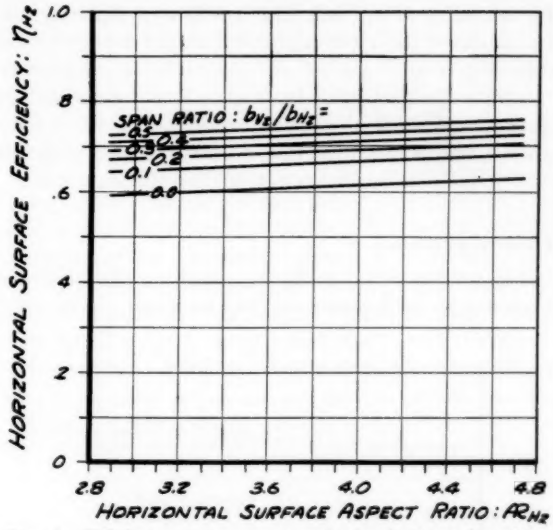

FIG. 4. Efficiency *versus* aspect ratio for horizontal surface with double vertical surfaces, for various span ratios.

to test at high and low values of α, both sets of data are included, each for the following ranges of angle of yaw:

$$\text{(a) } \psi = \pm 3^\circ; \quad \text{(b) } \psi = \pm(6^\circ \text{ to } 15^\circ)$$

It is apparent that there is little distinguishable difference between the single vertical surface efficiencies for the two regions. For the double vertical surfaces, however, the efficiency for region (b) is approximately 36 percent greater than that for region (a). For an aspect ratio of 1.5, the single vertical surface efficiency is approximately 127 percent greater than that for the double over region (a), and 67 percent over region (b). The difference between regions (a) and (b) for the double vertical surfaces is partially due to the fact that the fuselage has appreciable effect on the direction of airflow over the separate surfaces. The marked decrease of single vertical surface efficiency with aspect ratio may be partially explained by consideration of the fact that in the derivation for η_V, 5.5 was assumed

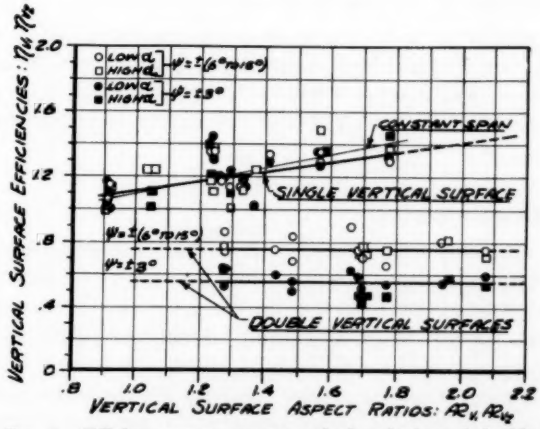
VERTICAL SURFACE EFFICIENCIES: η_{V_1} η_{V_2}
LOW α $\psi = \pm(6^\circ$ TO $15^\circ)$
HIGH α
LOW α $\psi = \pm 3^\circ$
HIGH α
CONSTANT SPAN
SINGLE VERTICAL SURFACE
$\psi = \pm(6^\circ$ TO $15^\circ)$
$\psi = \pm 3^\circ$
DOUBLE VERTICAL SURFACES
VERTICAL SURFACE ASPECT RATIOS: AR_{V_1} AR_{V_2}

FIG. 5. Efficiency *versus* aspect ratio for single and double vertical surfaces.

for the value of a_0; whereas, it is known that conventional airfoil theory breaks down at low aspect ratios, following a $\sin^2 \alpha$ relation.[3] In order to adequately illustrate the fact that little gain is accomplished in directional stability by adding vertical surface area for a given value of span, the line of constant span is shown on Fig. 5 for the single vertical surface efficiency case.

Elevator Efficiency

Fig. 6 gives elevator efficiency *versus* aspect ratio for empennages with single vertical surfaces. It is noted

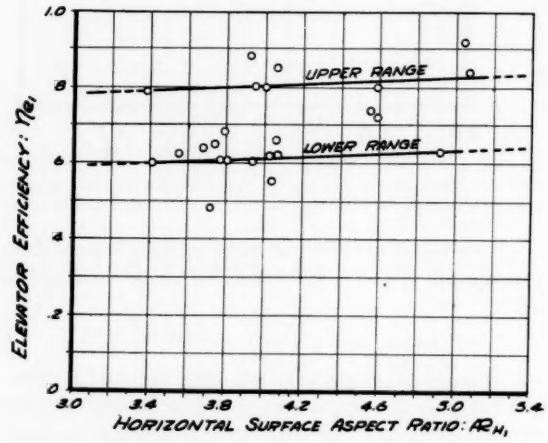

FIG. 6. Elevator efficiency *versus* aspect ratio for horizontal surface with single vertical surface.

that although the experimental points show considerable scatter, they seem to divide into an upper and lower efficiency range. The reason for this separation is not known at present. The elevator efficiencies for the horizontal surfaces with double vertical surfaces *versus* span ratio are given in Fig. 7 for a constant aspect ratio of 3.32. Although few experimental points are available, Fig. 7 indicates that a design value of η_{e_2} may be obtained from the product of η_{e_1} for a given aspect ratio and η_{H_2}/η_{H_1} for the corresponding span ratio. The value of η_{e_2} for $b_{V_2}/b_{H_2} = 0$ corresponds to the value of η_{e_1} (upper range) for $A.R._{H_1} = 3.32$. The variation of the curve from that point is determined from the product of η_{H_1} and the variation of η_{H_2}/η_{H_1} with the span ratio from Fig. 3.

Rudder Efficiency

Rudder efficiencies for single and double vertical surfaces are given in Fig. 8 for two angles of attack. It is noted that as in the case of η_V, the rudder efficiencies for both single and double vertical surfaces do not vary noticeably with angle of attack. It is apparent, however, that the rudder efficiency for the single vertical surface is approximately 55 percent greater than that for the double vertical surfaces.

Choice of Empennage Type

Using the static longitudinal and directional stability due to surfaces only, and the rudder effectiveness of the DC-4 empennage with triple vertical surfaces; comparisons are made between empennages with single and double vertical surfaces. The values upon which the comparison is based are as follows:

$$dC_{m_H}/dC_L = -0.266$$
$$dC_{\eta_V}/d\psi = -15.7 \times 10^{-4}$$
$$dC_n/d\delta_r = -12.1 \times 10^{-4}$$

Due to the fact that the DC-4 experimental points for vertical surface and rudder efficiencies do not fall exactly on the faired curves given in Figs. 5 and 8; the value given above for the static directional stability due to vertical surfaces only is approximately 11 percent higher than the experimental value, while the value given for rudder effectiveness is approximately 2 percent below the experimental value.

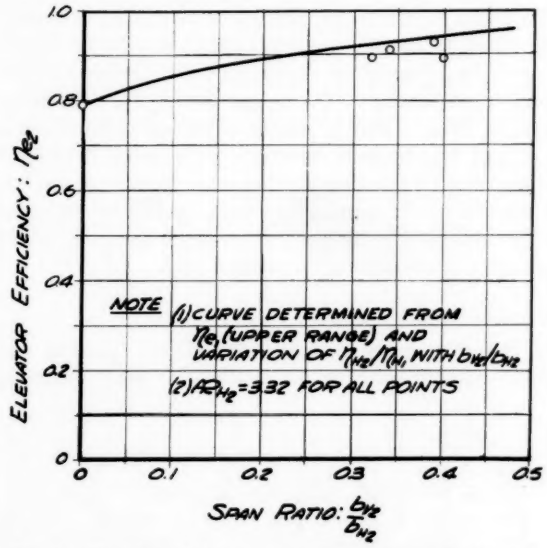
ELEVATOR EFFICIENCY: η_{e_2}
NOTE (1) CURVE DETERMINED FROM η_{e_1} (UPPER RANGE) AND VARIATION OF η_{H_2}/η_{H_1} WITH b_{V_2}/b_{H_2}
(2) AR_{H_2} = 3.32 FOR ALL POINTS
SPAN RATIO: $\frac{b_{V_2}}{b_{H_2}}$

FIG. 7. Elevator efficiency *versus* span ratio for horizontal surface with double vertical surfaces.

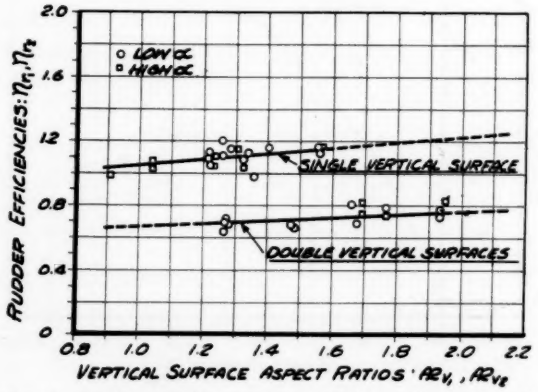

FIG. 8. Rudder efficiency *versus* aspect ratio for single and double vertical surfaces.

Ratios of horizontal and vertical surface areas to wing area giving constant static longitudinal stability with (1) constant static directional stability, or (2) constant rudder control, are plotted *versus* horizontal and vertical surface aspect ratios in Figs. 9 and 10.

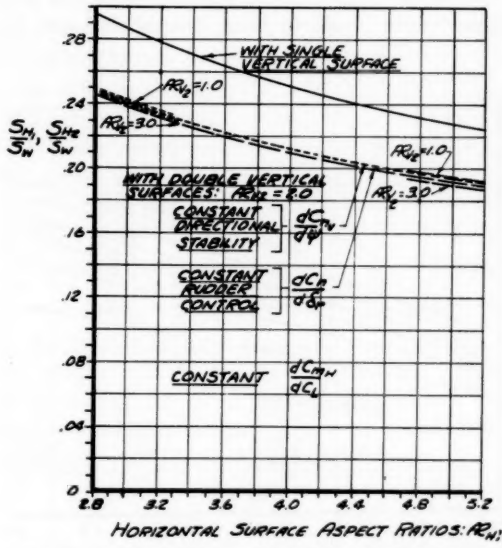
WITH SINGLE VERTICAL SURFACE
WITH DOUBLE VERTICAL SURFACES: AR_{V_2} = 2.0
CONSTANT DIRECTIONAL STABILITY
CONSTANT RUDDER CONTROL
CONSTANT
HORIZONTAL SURFACE ASPECT RATIOS: AR_{H_1}, AR_{H_2}

FIG. 9. Ratio of horizontal surface area to wing area for constant static longitudinal stability with single and double vertical surfaces, *versus* horizontal surface aspect ratio.

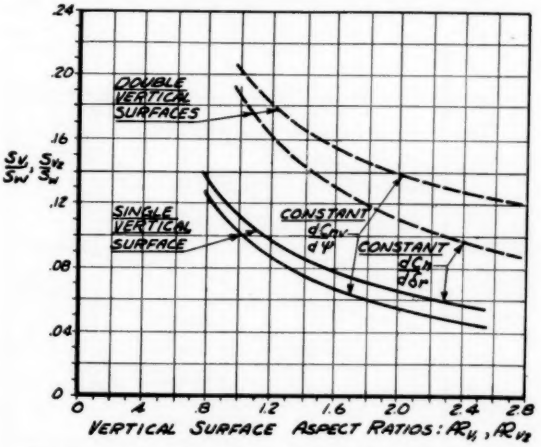

FIG. 10. Ratio of vertical surface area to wing area for constant static directional stability or rudder control, *versus* vertical surface aspect ratio.

It is apparent from an investigation of Fig. 9, that variation of double vertical surface aspect ratio has small effect on the required horizontal surface area. The variation, shown in Fig. 10, of vertical surface area with aspect ratio for single and double vertical surfaces gives the interesting result that for all aspect ratios, more single vertical surface area is required to give the desired rudder effectiveness than is required to give the desired directional stability. For the double vertical surfaces, more area is required to give the desired directional stability than is required to give the desired rudder control. This is brought about by the fact that for the double vertical surfaces, the rudder efficiency is greater than the vertical surface efficiency; whereas, in the case of the single vertical surface, the vertical surface efficiency is greater than the rudder efficiency.

Fig. 11 shows that for the conditions imposed, constant static longitudinal and directional stability, the area required for an empennage with double vertical surfaces, given constant values of horizontal and vertical surface aspect ratio, is always greater than that area required with single vertical surface. On the basis of constant static longitudinal stability and rudder effectiveness, the comparison of the required empennage area is more favorable for the double vertical surface case (Fig. 12). If a comparison is made on the basis of the same horizontal and vertical surface aspect ratios,

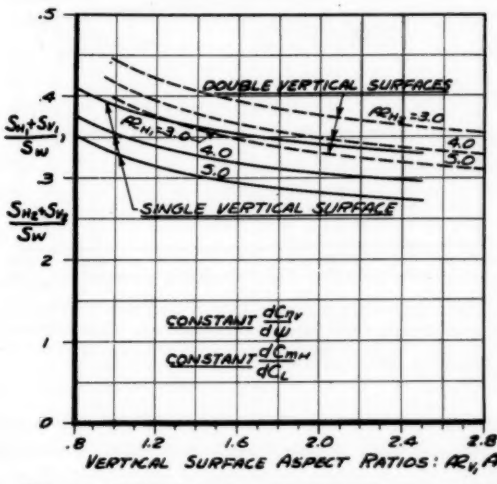

FIG. 11. Ratio of empennage area to wing area for both constant static longitudinal and directional stability, *versus* vertical surface aspect ratio.

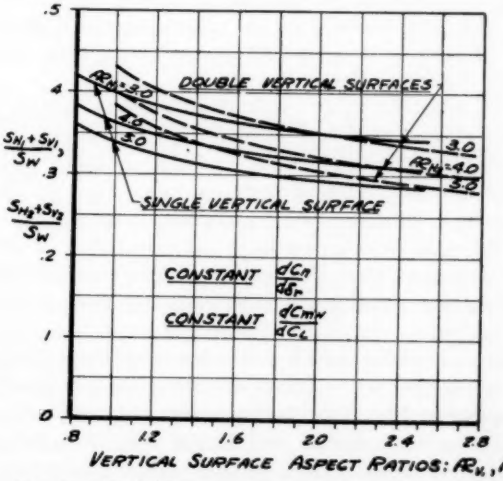

FIG. 12. Ratio of empennage area to wing area for both constant static longitudinal stability and rudder effectiveness, *versus* vertical surface aspect ratio.

it is seen that the empennage area required becomes equivalent for the following values of aspect ratio:

$$A.R._V = 2.0 \text{ for } A.R._H = 3.0$$
$$A.R._V = 2.4 \text{ for } A.R._H = 4.0$$

If, however, a fairer comparison is to be made, the maximum values of single and double vertical surface aspect ratios indicated by existing airplanes should be taken into account. These upper values are $A.R._{V_1} = 1.5$, $A.R._{V_2} = 2.0$. If a comparison of the empennage area required for constant dC_{m_H}/dC_L, constant $dC\eta_V/d\psi$, or constant $dC_n/d\delta_r$ is made, Fig. 13 is obtained.

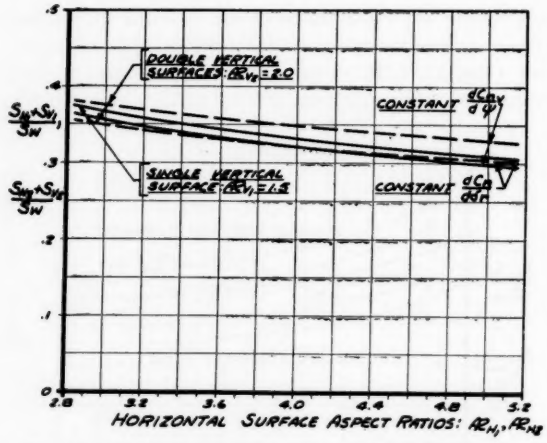

FIG. 13. Ratio of empennage area to wing area for constant static longitudinal stability and constant static directional stability or rudder effectiveness, comparing single and double vertical surfaces of aspect ratios 1.5 and 2.0, respectively.

Assuming a horizontal surface aspect ratio of 4, it is seen that for constant static longitudinal and directional stability, the required empennage area with double vertical surfaces is approximately 8 percent greater than that required with single vertical surface; for constant static longitudinal stability and constant rudder control, the area required for an empennage with single vertical surface is 3 percent greater than that with double vertical surfaces.

With constant static longitudinal stability and horizontal surface area, it is possible to obtain equivalent aspect ratios for horizontal surfaces equipped with single or double vertical surfaces, using Fig. 14. As an example, for $A.R._{H_2} = 4.0$ and a span ratio, $b_{V_2}/b_{H_2} = 0.4$, the equivalent aspect ratio value is $A.R._{H_1} = 6.0$. It is apparent that the reverse process can be performed, thus obtaining a value of $A.R._{H_2}$ from $A.R._{H_1}$ and b_{V_2}/b_{H_2}.

The basic differences between an empennage design employing the use of single or double vertical surfaces is given in Fig. 15. This chart presents rudder effectiveness ratio with double and single vertical surfaces, for various values of single vertical surfaee aspect ratio, having designed for constant static directional stability. It also presents static directional stability ratio with double and single vertical surfaces, having designed for constant rudder control. It is seen that for $A.R._{V_1} = 1.5$ and $A.R._{V_2} = 2.0$, having designed for constant $dC\eta_V/d\psi$, the rudder effectiveness of the double vertical surfaces will be approximately 52 percent greater than that of the single vertical surface. Likewise with the same values of aspect ratio, having designed for

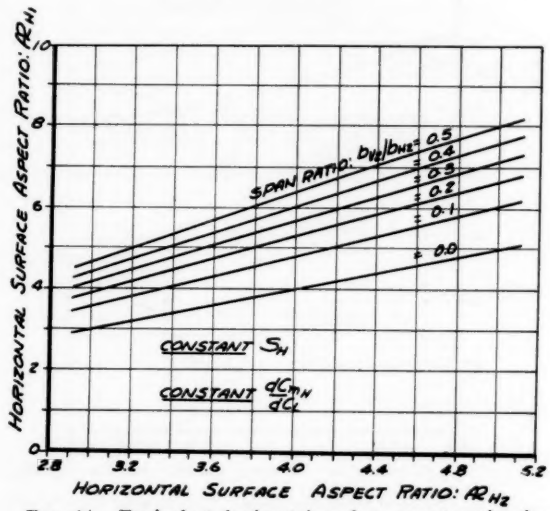
HORIZONTAL SURFACE ASPECT RATIO: AR_{H_1}
SPAN RATIO: b_{V_2}/b_{H_2} = 0.5, 0.4, 0.3, 0.2, 0.1, 0.0
CONSTANT S_H
CONSTANT $\frac{dC_{m_H}}{dC_L}$
HORIZONTAL SURFACE ASPECT RATIO: AR_{H_2}

FIG. 14. Equivalent horizontal surface aspect ratios for single and double vertical surface designs to give constant static longitudinal stability and horizontal surface area.

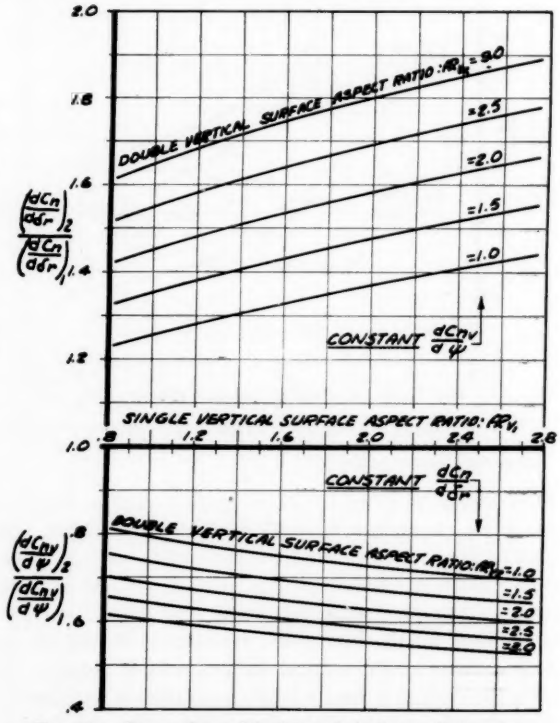
DOUBLE VERTICAL SURFACE ASPECT RATIO: AR_{V_2} = 3.0, 2.5, 2.0, 1.5, 1.0
CONSTANT $\frac{dC_n}{d\delta_r}$
SINGLE VERTICAL SURFACE ASPECT RATIO: AR_{V_1}
CONSTANT $\frac{dC\eta_V}{d\psi}$
DOUBLE VERTICAL SURFACE ASPECT RATIO: AR_{V_2} = 1.0, 1.5, 2.0, 2.5, 3.0
$\left(\frac{dC_n}{d\delta_r}\right)_2 / \left(\frac{dC_n}{d\delta_r}\right)_1$
$\left(\frac{dC\eta_V}{d\psi}\right)_2 / \left(\frac{dC\eta_V}{d\psi}\right)_1$

FIG. 15. Comparison of double and single vertical surfaces. (1) Rudder effectiveness ratio for constant static directional stability. (2) Static directional stability ratio for constant rudder effectiveness.

constant $dC_n/d\delta_r$ the static directional stability of the double vertical surfaces will be 34 per cent less than that of the single vertical surface. These values bring out the essential differences between an empennage with single or double vertical surfaces.

Control Hinge Moments

Single and Double Rudders Comparison

In order to complete the comparison of empennages with single and multiple vertical surfaces, it is necessary that a comparison be made of the hinge moments for constant rudder control. From reference 1, the expression for the rudder hinge moment per degree may be taken as follows:

$$\frac{dC_{h_r}}{d\delta_r} = \left[\frac{\partial C_{h_r}}{\partial C_{L_V}} \frac{dC_{L_V}}{d\psi} \lambda_r + \frac{\partial C_{h_r}}{\partial \delta_r}\right] \frac{\pi}{180}$$

If the vertical surface efficiency, η_V, is inserted in the first term of the above equation, to obtain consistency in comparing the single and double rudders, the expression for hinge moment per degree of rudder, divided by the dynamic pressure, may be written:

$$\frac{1}{q} \frac{dH_{m_r}}{d\delta_r} = \left[\eta_V \frac{\partial C_{h_r}}{\partial C_L} \frac{dC_{L_V}}{d\psi} \lambda_r + \frac{\partial C_{h_r}}{\partial \delta_r}\right] \frac{\pi}{180} S_r t_r$$

The expression $(1/q)dH_{m_r}/d\delta_r$ is plotted *versus* vertical surface aspect ratio for constant percent aerodynamic balance and constant rudder effectiveness in Fig. 16. This chart indicates that for a given value of

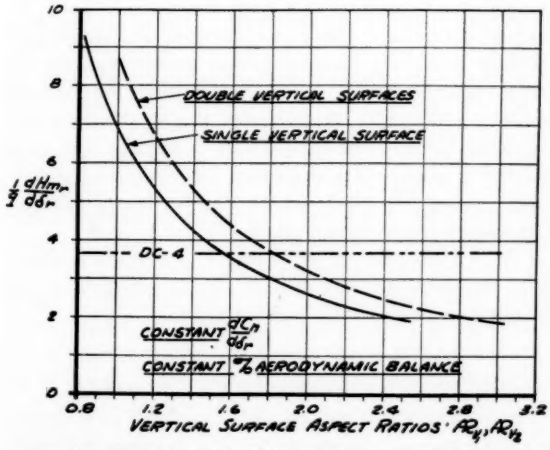

FIG. 16. Ratio of rudder hinge moment per degree to dynamic pressure, *versus* aspect ratio for single and double vertical surfaces giving constant rudder effectiveness.

aspect ratio, the rudder hinge moment is greater for the double vertical than for the single vertical surface. If, however, a comparison is made with $A.R._{V_1} = 1.5$ and $A.R._{V_2} = 2.0$, it is seen that the rudder hinge moment of the double vertical surfaces will be approximately 16 percent less than that of the single vertical surface. The value of $(1/q)dH_{m_r}/d\delta_r$ for the DC-4 is given on Fig. 16 showing that, for the same hinge moment, $A.R._{V_1}$ (DC-4) should be 1.57, $A.R._{V_2} = 1.83$.

Hinge Moment Reduction

Four methods of control surface moment reduction will be discussed briefly.

(1) *Aerodynamic Balance* forward of the movable control surface hinge line (Fig. 1) is the most commonly used method, giving adequate force reduction for airplanes up to a gross weight of approximately 25,000 pounds. Limiting aerodynamic balance is determined by a combination of icing conditions, and the fact that rotational velocities for the angle of attack on a control surface is often sufficient to cause over-balance in some region.

(2) *Balancing tabs* give a simple method of adjusting the aerodynamic balance by changing the relationship between tab and control surface angles. Reduction in control surface effectiveness and control free stability results. By proper design, the balancing tab presents a method of force reduction not subject to dangers of over-balance from icing.

(3) *Servo tabs* offer extreme control force reduction, with adequate control at high speeds, questionable control at low speeds. Careful designing is required because of the fact that two control surfaces are free.

(4) *Power boost* offers a method of securing any desired degree of control force reduction, application at present being limited to the size of airplane for which, after power boost failure, adequate manual control is still possible for emergency conditions.

Hangar Clearance

To show the effect on the overall height of the airplane when equipped with single or double vertical surfaces, the height of the DC-4 with tricycle gear is compared with various empennage installations in accordance with the former conditions: constant dC_{m_H}/dC_L, $dC\eta_V/d\psi$, or $dC_n/d\delta_r$. From Fig. 17, it can be concluded that for constant values of static directional stability or rudder control, the triple vertical surface maintains the lowest possible overall height of the airplane.

Effect of Design Variations

Horizontal Surface Tips

For an empennage with double vertical surfaces one method of increasing the horizontal surface area is the addition of tips outside the double vertical surfaces. The results of wind-tunnel tests on two representative models show the effect of horizontal surface tip addition to be: (1) An increase in static longitudinal stability equivalent to that which would be obtained by addition of the same increment of horizontal surface area inside the double vertical surfaces, keeping the

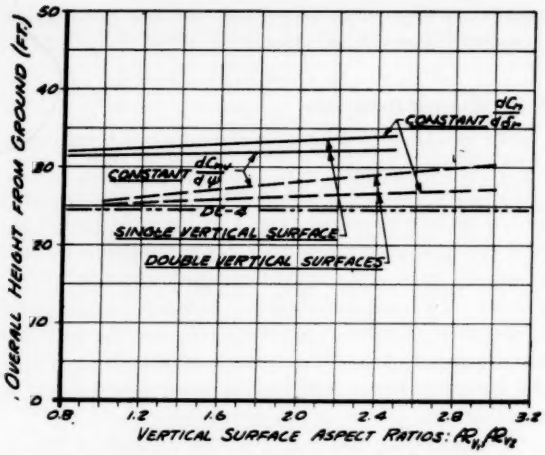

FIG. 17. Overall height of DC-4 equipped with either single or double vertical surfaces giving constant static directional stability or rudder effectiveness, *versus* vertical surface aspect ratio.

aspect ratio constant. Approximately 50 percent of the increase in static longitudinal stability caused by the addition of the tips would be obtained by addition of an equivalent amount of area inside the double vertical surfaces, keeping the span constant. (2) The addition of a given increment of area as a horizontal surface tip gives approximately twice the parasite drag as the amount of area added inside the double vertical surfaces.

Horizontal Surface Cut-Outs

For empennages with double vertical surfaces it is necessary to sacrifice a slight amount of elevator area in order to provide for adequate rudder travel. This may by done in several ways. Two arrangements are shown in Fig. 1, one representing the elevator cut back perpendicular to the hinge line, the other representing the elevator cut at an angle, leaving a triangular section of fixed horizontal surface. If this triangular portion is omitted, the reduction in static longitudinal stability is twice that which would be expected from the area decrease.

Location of Double Vertical Surfaces

For ground clearance, in some instances it becomes necessary to use double vertical surfaces which are asymmetrically located with respect to the horizontal surface tip chords. From wind-tunnel model tests on various types of double vertical surfaces, no consistent difference could be distinguished between static directional stability and rudder effectiveness for double vertical surfaces symmetrically or asymmetrically located with respect to the horizontal surface tip chords. According to theory[4] this is reasonable since only a very slight increase in lift is experienced from shifting the endplate attachment from symmetrical to one-sided. It is apparent that greater bending moments result from an unsymmetrical attachment, thus making the structural problem more difficult.

Horizontal Surface Dihedral

Although the primary reason for the horizontal surface dihedral on the DC-4 was to maintain symmetrical double vertical surfaces simultaneously with ground and hangar clearance, a secondary effect was obtained in increased directional stability. Theoretical analysis indicates that the additional yawing moment from the horizontal surface dihedral varies as the square of the dihedral angle. The few representative tests available at present indicate that the theory can be used conservatively. The formula is

$$\Delta \frac{dC_n}{d\psi} = -\left(\frac{\pi}{180}\right)^3 \frac{l_H}{b} \frac{S_H}{S_W} \frac{a_0}{1 + a_0/\pi\, A.R._H} \gamma^2$$

CONCLUSION

From the present study of the relative merits of empennages with single and double vertical surfaces the following conclusions are drawn.

(1) The double vertical surfaces offer a method of obtaining a high degree of rudder control without excessive static directional stability, while the single vertical surface offers a high degree of static directional stability without excessive rudder control.

(2) On the basis of maximum aspect ratios used on single and double vertical surfaces for existing designs: namely, 1.5 and 2.0, the total empennage area required for constant static longitudinal and directional stability is slightly greater for the double than for the single vertical surface. For constant static longitudinal stability and rudder effectiveness, the total empennage area with double vertical surfaces is slightly less than that with single vertical surface for horizontal surface aspect ratios less than 4.0, greater for horizontal surface aspect ratios greater than 4.0.

(3) An empennage with multiple vertical surfaces gives substantially less overall airplane height in case hangar clearance is an important factor.

REFERENCES

[1] Wenzinger, Carl J., *Pressure Distribution over an Airfoil Section with a Flap and Tab*, Fig. 11, N.A.C.A. Technical Report No. 574, 1936.

[2] Millikan, Clark B., *On the Results of Aerodynamic Research and Their Application to Aircraft Construction*, Journal of the Aeronautical Sciences, Vol. 4, No. 2, pages 43–53, December, 1936.

[3] Bollay, William, *A Theory for Rectangular Wings of Small Aspect Ratio*, Journal of the Aeronautical Sciences, Vol. 4, No. 7, pages 294–296, May, 1937.

[4] Mangler, W., *The Lift Distribution of Wings with End Plates*, N.A.C.A. Technical Memorandum No. 856, 1938.

Toward a Rational Method of Tail-Plane Design

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ABSTRACT

The framework of a method for the design of tail planes is outlined, and both the extent of the existing knowledge available for its application and the important omissions are discussed. The method differs from the existing one most particularly in that the separate variables that influence the tail performance are given greater individual attention.

Experimental results are presented in some cases to show their relation with certain theories, or to illustrate the general nature of a phenomenon. It is concluded that further extensive research is required before a complete design solution of the tail-plane problem can be made.

INTRODUCTION

STUDY has been directed for the past few years in the laboratory of the N.A.C.A. toward the development of a rational method of tail-plane design. The method is called "rational" to imply that the steps in its development are reasonable and logical, and it should not be inferred that the existing empirical systems are considered irrational.

Current methods for tail-plane design incorporate empirical "tail efficiency factors" into which all the separate wake and interference variables are grouped. The downwash angles are further empirically evaluated without taking sufficient consideration of the effects of wing shape, flap conditions, or tail position relative to the wing. These methods serve with some accuracy for conventional airplane arrangements but are admittedly inadequate for cases in which flaps are deflected or large slipstream effects occur. In this study an attempt has been made to evaluate separately the variables that affect the tail-plane performance as functions of the airplane arrangement and the flight conditions. The method indicates the steps to be followed in the design of tail planes to provide specified tail moments and is not concerned with the separate problem of specifying the tail characteristics that will provide desirable flight characteristics.

The purpose of this paper is to outline the framework for this design system and to show the extent of its present development. Thus far, particular emphasis has been placed on the study of the airflow in the region behind the wing, and general methods have been developed for predicting the downwash and wake behind plain and flapped airfoils.[1] The results are, in all cases, based on experimental researches, however generalization of the method has been afforded by the theory. These results are presented in a form which it is hoped will be readily applicable to design.[2]

Presented at the Airplane Design Session, Seventh Annual Meeting, I. Ae. S., January 27, 1939.

STATEMENT OF PROBLEM

Since the purpose of this paper is to consider only the contribution of the tail to the airplane, a discussion of the stability and balance equations which include the contributions of the wings, propeller, etc., is avoided.

The characteristics of the airplane tail that are required for flight-handling calculations are as follows:

(1) Tail force and effectiveness, C_{N_t} and $dC_{N_t}/d\alpha_t$.
(2) Elevator effectiveness, $dC_{N_t}/d\delta_e$.
(3) Tail moment, $C_{m_{0_t}}$.
(4) Maximum normal force, $\pm C_{N_{t_{max.}}}$
(5) Hinge moments and balance effectiveness, C_h and $dC_{h_e}/d\delta_e$.

It will be noted in the foregoing that normal-force coefficient, C_{N_t}, is used while chord-force coefficient, C_c, is omitted. This approximation does not introduce an appreciable error. Further, since the emphasis has thus far been placed on a study of the horizontal tail surfaces, reference will be made largely to elevators. Much of the discussion will also apply to rudder design.

The foregoing characteristics of the tail as installed on the airplane must be calculable for the entire range of airplane flight attitudes. They depend, therefore, on the airplane characteristics and are functions of the following:

(1) Aerodynamic characteristics of the tail detached from the airplane.
(2) Arrangement of the tail on the airplane.
(3) Direction of airflow in region of tail.
(4) Airflow velocity in region of tail.

The design problem involves, first, the evaluation of the foregoing variables, and, second, the determination of the dependence of the tail characteristics on their values. To illustrate, suppose that the average velocity at the tail is evaluated as 1.5 times the free-stream velocity; then the values of the tail characteristics, $dC_N/d\alpha_t$, $dC_N/d\delta_e$, etc., which correspond to this slipstream velocity must be determined.

Aerodynamic Characteristics of Detached Tail Planes

The available aerodynamic data on a large number of horizontal tail planes have recently been collected, and a correlation of these experimental results with the airfoil theory has been made.

The normal force on a tail plane can be expressed in the form

$$C_{N_t} = K(\alpha_t + \tau\delta_e) \qquad (1)$$

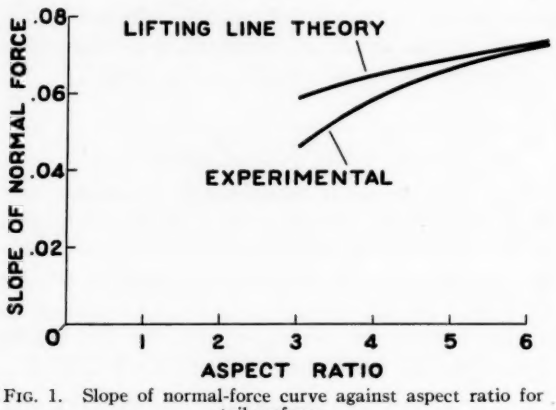

Fig. 1. Slope of normal-force curve against aspect ratio for tail surfaces.

The value of the tail effectiveness factor, K, or $dC_{N_t}/d\alpha_t$, depends mainly on the aspect ratio and, according to lifting-line theory, this slope should be approximately $a_0/(1 + 57.3\, a_0/\pi/A)$. The experimental slope, however, decreases with aspect ratio more rapidly than does the value of this expression (Fig. 1). Such behavior has been predicted by theoretical considerations and has been measured in other investigations on low-aspect-ratio airfoils. The slope predicted by the lifting-line theory should therefore be reduced by a factor, m, so that

$$dC_{N_t}/d\alpha_t = m \quad a_0/(1 + 57.3\, a_0/\pi A)$$

Values of m for various aspec tratios are given in Table 1.

Table 1

A	m	A	m
3	0.79	5	0.97
4	0.92	6	0.99

The value of the lift-curve slope, a_0, is a function of the airfoil section and results may be obtained from infinite aspect ratio airfoil data. A typical value of a_0 for a 9 percent thick, symmetrical airfoil at $R = 3 \times 10^6$ is 0.93 per degree. Variations in chord distribution and cutouts to accommodate the rudder do not seriously affect the value of $dC_{N_t}/d\alpha_t$.

The addition of end plates to the horizontal tail increases the tail effectiveness. According to the theory of wings with endplates, which has been substantiated by experiments,

$$\frac{dC_{N_t}}{d\alpha_t} = \frac{a_0}{1 + r\, a_0 \times 57.3/\pi A}$$

Values of r for various ratios of endplate height, h, to tail span, b_t, are given in Table 2.

Table 2

h/b_t	r	h/b_t	r
0	1.0	.3	0.65
.1	0.84	.4	0.58
.2	0.72	.5	0.53

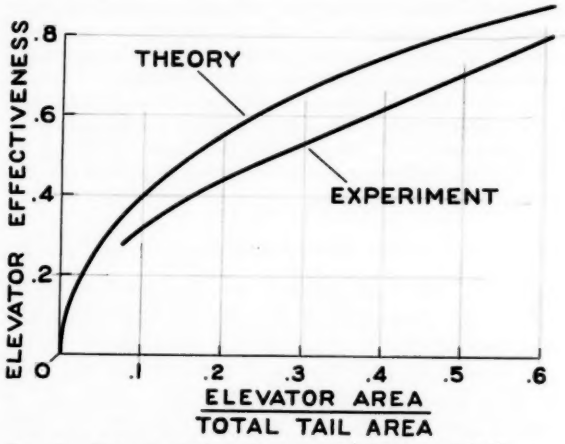

Fig. 2. Plot of relative elevator effectiveness, $dC_N/d\delta_e = dC_{N_t}/d\alpha_t$, against relative elevator area, S_e/S_t.

The parameter, τ of Eq. (1) is the ratio of the effectiveness of a change in elevator angle δ_e to a change in tail angle α_t and is a function mainly of the ratio S_e/S_t of the elevator area to the total tail area. A comparison of the experimental and theoretical values of τ is shown in Fig. 2. The average of the experimental values are about 70 to 80 percent of the theoretical. The gap between the elevator and the stabilizer decreases the elevator effectiveness and sealing the gap may increase the experimental values shown in Fig. 2 by as much as 10 percent.

The pitching-moment coefficient of the tail itself, $C_{m_{t_0}}$, is of interest for flight conditions in which large deflections of the elevator occur. The moment coefficient about the aerodynamic center is a function of S_e/S_t and δ_e, and typical values for a tail plane with $S_e/S_t = 0.35$, are given in Table 3.

Table 3

δ_e (deg.)	$C_{m_{t_0}}$	δ_e (deg.)	$C_{m_{t_0}}$
−30	0.31	10	− 0.07
−20	0.22	20	− 0.18
−10	0.10	30	− 0.50
0	0.01		

The coefficient $C_{m_{t_0}}$ is based on the tail area. The aerodynamic center remained at about the 0.25 chord position of the average chord for deflection up to 20°.

The maximum normal force of the tail, $C_{N_{t_{max.}}}$, is of interest for some designs. Although experimental data for tails at high Reynolds Number are rare, the available data indicate that the section thickness is an important factor. The flap effectiveness for 0.20 chord flaps increases almost linearly with thickness. The gap between the stabilizer and the elevator should also be small to avoid large reductions in maximum force. With a conventional offset-hinge balance of 0.25 c_e, the effectiveness of the elevator for increasing the maximum normal force decreases after 10° deflection and almost ceases for deflections greater than 20°. This effect is due to the protrusion of the balance above the surface, and is less marked for cases in which the balance is tapered in section.

The discussion of elevator hinge moments must necessarily be abbreviated. The theoretical hinge-moment coefficient for unbalanced elevators may be expressed in the form

$$C_{h_e} = uC_{N_t} + v\delta_e$$

The values of the parameters u and v may be derived by means of thin airfoil theory as functions of the chord ratio c_e/c_t. Experimental studies have shown the values of u to vary from 0.5 of the theoretical values for small values of c_e/c_t to 0.8 of these values at large chord ratios. The experimental values of v are in much better agreement with theory and average experimental values are approximately 0.9 of the theoretical. The discussion of elevator balances is reserved for later papers.

Arrangement of Tail Assembly

The fuselage and the vertical tail cause an effective reduction in the area of the horizontal tail surface, the amount depending on the geometry of the particular tail assembly. In some constructions, the horizontal tail lies above the fuselage and passes through the vertical tail; in such cases it is found that the area of the horizontal tail must be considered reduced by the amount removed by the vertical tail, usually about 5 percent. In another type of construction, the horizontal tail passes through the center of the fuselage. It has been found for such cases, as for the usual case of a wing passing through a fuselage, that no reduction in the effective area of the tail surface occurs. In fact, if the elevator fits snugly against the side of the fuselage, it should also be considered for small deflections to be carried through a fuselage. The type of construction in which the horizontal tail is located at the top of the fuselage and at the bottom of the vertical tail surface is probably intermediate between the two types just discussed, but data are not available for this case.

Air Flow Direction in Tail Region

The direction of the air flow in the tail region is the resultant of the flow due to the wing, the fuselage and wing-fuselage juncture, and the propeller. These flows are interdependent but, for many flight conditions, the effects of one or another may preponderate and it is necessary to consider them separately.

Wing Downwash

The downwash behind a wing is mainly a function of the wing loading and is created by the associated vortex system. The vortex system consists of the lifting vortex, which is considered localized at the quarter-chord line, and the vortex sheet that is shed at the trailing edge. As a result of the air motion that the vortex system itself creates, the trailing vortex sheet is displaced downward behind the wing and deformed.

The strength of the vortex sheet is directly proportional to C_L; hence, the downwash and the displacement of the vortex sheet are likewise proportional to C_L. In the event a flap is added to the wing, the strong vortex that is shed at the flap tip serves to increase the downwash inboard of the flap tip and decrease it outboard of the tip.

Recognition of these flow concepts followed comprehensive experimental investigations and it has become possible to predict theoretically a pattern of downwash angles behind the wing that is in excellent agreement with the experiment.[1] Design charts showing the downwash angles, ϵ, and downwash displacement behind wings of 15 practical shapes including flaps of several spans have been calculated and are given in reference 2. A typical contour map of these downwash

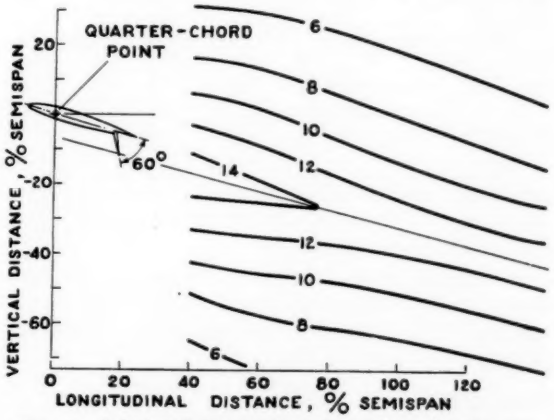

FIG. 3. Calculated downwash-angle contours for the symmetry plane of an airfoil. Taper, 3:1; aspect ratio, 9; 70 per cent span split flap; δ_f, 60°; C_{L_w}, 1.3; C_{L_f}, 0.8.

angles as computed by the method of reference 1 for a 3:1 taper wing of aspect ratio 9 with a 70 percent span-split flap deflected 60° is shown in Fig. 3. The use of the design charts enables the variables of wing shape, aspect ratio, flap condition, and tail position to be accurately taken into consideration. The effects of the

aspect ratio, taper ratio, and flap span on the maximum downwash angle at a distance 0.8 semi-span behind the quarter-chord point of the airfoil are shown in Figs. 4 and 5. The downwash angles are shown for $C_L = 1$ and, as expected, the values increase with the

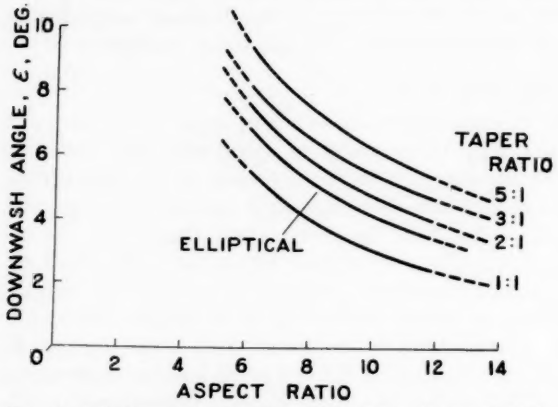

FIG. 4. Maximum downwash angles, 0.8 semi-span behind quarter-chord point of root section. Plain wing; C_{L_w}, 1.0.

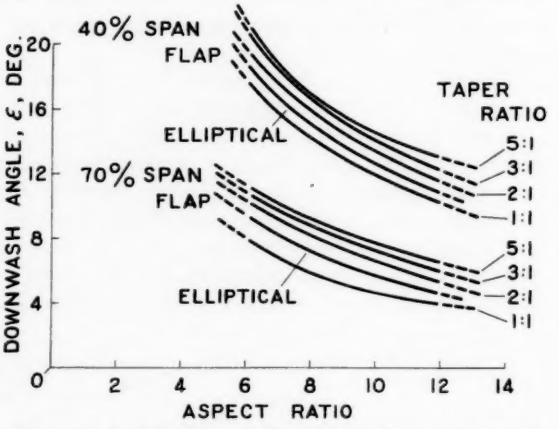

FIG. 5. Contribution of flaps to maximum downwash angles, 0.8 semi-span behind quarter-chord point of root section, C_{Lf}, 1.0.

increasing taper ratio, decrease with increasing aspect ratio, and for the same total lift increment are largest for the short-span flap.

Recognition is also given in reference 2 to the variation of the downwash angles over the span of the tail, to the downwash behind stalled wings, and to the effect of the wake on the downwash.

Fuselage Downwash

The results of several investigations are available in which the fuselage downwash angles were determined by tests of fuselage-tail combinations without the wings. In one instance,[3] tests were made with fuselages of several different shapes and with tail planes of two aspect ratios. The data showed that the maximum change in the average downwash over the tail for a well-shaped fuselage at high angle of attack was of the order of 1°.

Similar tests in the N.A.C.A. full-scale wind tunnel on a standard fuselage-tail combination (including windshield, engine exhaust stacks, etc.) showed an average downwash over the tail which varied from about 1° at high-speed angles of attack to 3° at stalling angles. In this case, the tail was above the fuselage so the downflow was a maximum.

Consideration of the fuselage downwash without reference to the wing flow leads, however, to erroneous conclusions. The effective angle of attack of the fuselage in the presence of the wing downwash is α-ϵ. For flapped, tapered wings, the value of ϵ, the wing downwash angle, is at the fuselage about equal to α, so that the fuselage is effectively at its zero angle of attack. The flow follows the fuselage in this condition, and it will contribute little to the downwash. If the tail is mounted on the upper side of the fuselage, the downwash may be slightly increased by the downward motion of the air following the contour of the streamline body. An opposite effect may occur if the tail is mounted on the bottom of the fuselage.

In order to verify the reasoning, results are given for two airplanes (Figs. 6 and 7) in which the average downwash over the tail was determined by calculations from measurements of pitching moments and tail effectiveness. Both cases represent ideal midwing fuse-

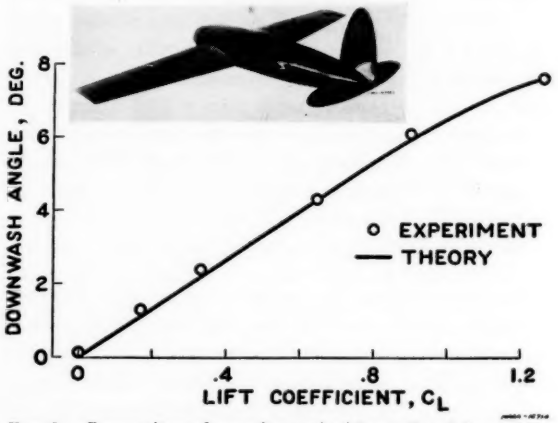

FIG. 6. Comparison of experimental with predicted downwash angle at the tail of a mid-wing airplane model. Unflapped wing.

lage combinations with the tail plane located at the center of the fuselage. The agreement between the experimental downwash angles and the wing downwash angles computed by the charts of reference 2 is excellent, which indicates that neither the fuselage nor the wing-fuselage juncture materially affects the downwash at the tail. Similar results were obtained in the variable-density wind tunnel for high and low wing positions in which maximum variations of 1° were found between the experimental and the computed downwash angles. A report on this work is in process of publication. It may be concluded for ideal wing-fuselage combinations, for cases in which the value of ϵ is about equal to α, that the fuselage downwash

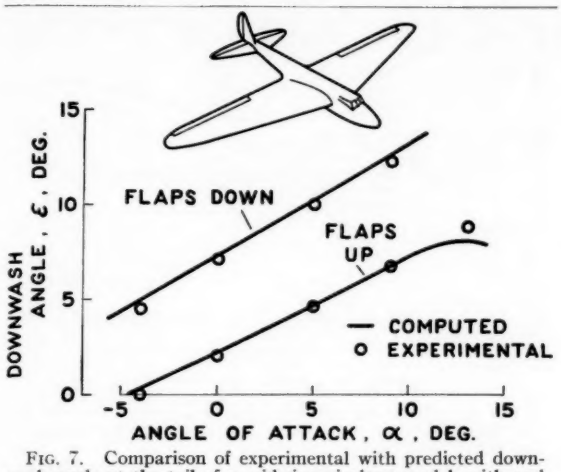

FIG. 7. Comparison of experimental with predicted downwash angle at the tail of a midwing airplane model, with and without flaps.

angle may be neglected. This condition represents, in fact, the usual case of the modern, efficient monoplane.

Several cases have also been tested[4] that demonstrate the large effect of a poor wing-fuselage juncture on the downwash at the tail. The average downwash angle over the horizontal tail of a low-wing monoplane at a high angle of attack was decreased about 7° by a bad juncture without a fillet. With a slipstream flowing over the poor juncture, the difference in downwash angle between the filleted and unfilleted case was reduced to 1°. Further experiments are required before the effects of poorly shaped wing junctures may be completely evaluated.

Slipstream Downwash

The change in airflow direction at the tail due to the propeller slipstream may be considered as a change in the average downwash angle and a change in the distribution of the downwash. The former depends primarily on the angle of the thrust axis and the thrust coefficient, and the latter is a function of the torque. Both effects vary widely with the arrangements of the propeller, the wing, and the fuselage; and as yet no satisfactory general solution of the problem has been obtained. Experimental results have been obtained on various phases of the problem, which are briefly reviewed.

Glauert[5] gives experimental results for a propeller tested alone in which the average value of the downwash was obtained by means of a vane behind the propeller. The value of the downwash angle divided by the angle of attack, ϵ/α, varied from about 0.05 at $V/nD = 1.0$ to 0.35 at $V/nD = 0.5$. These results indicate, for the high-speed flight condition (large values of V/nD), that the effect of the propeller inclination on the average downwash angle is small. Analysis and tests made by Ferrari[6] on the same problem indicate that the downwash angle for an inclined propeller may be computed with considerable accuracy from the theory. These results are in essential agreement with those of Glauert. The effects of the slipstream on the downwash of the wing, not including the effect of the propeller inclination, have been measured by Stüper.[7] The results indicate that the downwash angles increase slightly with the thrust coefficient, but the downwash increment is almost independent of the angle of attack of the wing.

Tests have been made in the N.A.C.A. full-scale tunnel in which the average downwash angle at the tail have been measured for several airplanes at several propeller thrust conditions. The direction of the airflow in the transverse plane at the tail is shown by arrows (Figs. 8 to 11), the length of which indicates the angular deflection. These results include the change in the downwash due to propeller inclination, the deflection due to the wing, and the effects of the rotation of the slipstream.

At large propeller torque coefficients, the slipstream rotation may have a considerable influence on the distribution of the downwash. A cross-plot of Figs. 10 and 11 showing the downwash angle at the elevator hinge line is shown in Fig. 12. This airplane was equipped with a pusher propeller so that the wing did not reduce the slipstream rotation. The result on Fig. 9 for the single-engine, high-wing monoplane shows that the rotation of the propeller slipstream is large despite the tractor propeller location. The propeller slipstream in this case passes, for the most part, below the wing. Results are shown in reference 7 for the case of a propeller located on the wing chord with a ratio of propeller-diameter to wing chord of 0.75. The downwash angles due to the rotation are largely reduced in comparison with the values measured without the wing, and the effect is shown to vary greatly with the angle of attack of the wing.

The effect of the wing in reducing the slipstream rotation is also dependent on the propeller diameter-wing chord ratio and extensive research is needed on this subject.

AIRFLOW VELOCITY IN TAIL REGION

The air speed in the region of the tail may be influenced by the wing wake, the fuselage boundary layer, and the propeller slipstream.

Wing Wake

The wake may be defined as the region behind the wing in which the skin-friction drag is manifested as a decreased total head. The wake, which has its source in the boundary layer at the wing trailing edge, widens with increasing distance downstream from the wing and becomes less intense. For tail calculations it is necessary to know the wake location with reference to the tail, and the wake dimensions. The wake location

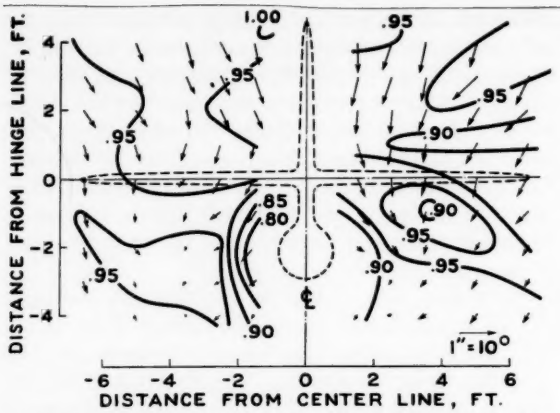

FIG. 8. Dynamic pressure (q/q_0) and airflow direction in the plane of the elevator hinge line. Parasol monoplane; α_i, 4.2°; C_L, 0.506; power off.

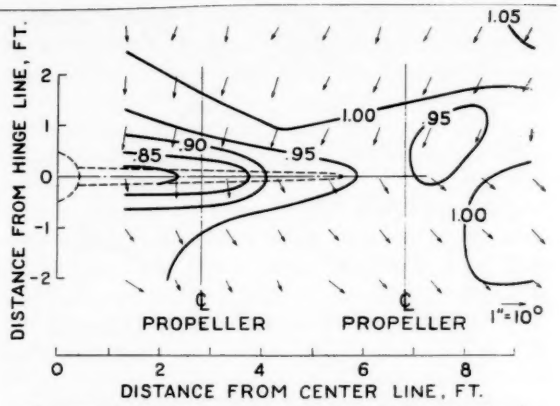

FIG. 10. Dynamic pressure (q/q_0) and airflow direction in the plane of elevator hinge line. Four-engine pusher airplane; α_i, 10.2°; C_L, 1.08.

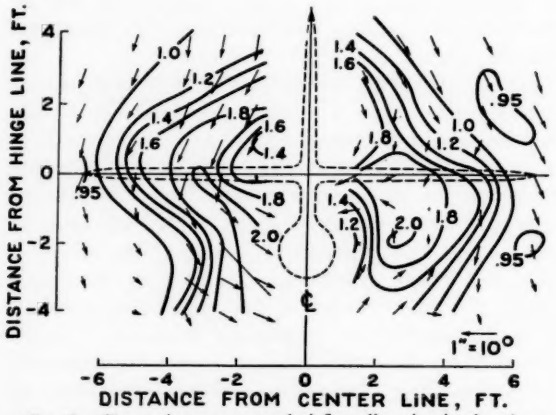

FIG. 9. Dynamic pressure and airflow direction in the plane of the elevator hinge line. Parasol monoplane, α_i, 3.8°; C_L, 0.543, T_{C_0}, 0.134.

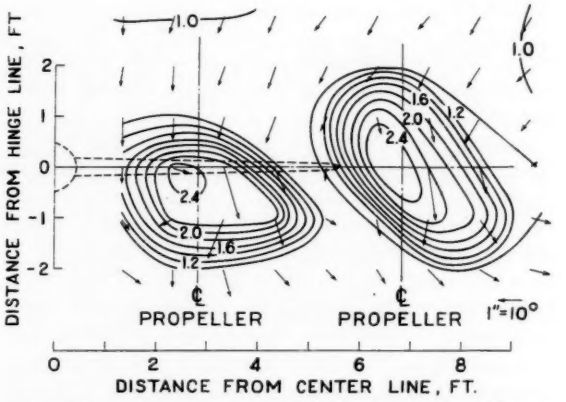

FIG. 11. Dynamic pressure and airflow direction in the plane of the elevator hinge line. Four-engine pusher airplane; α_i, 10.2°; C_L, 1.12; T_{C_0}', 0.205; V/nD = 0.470.

has been shown to be a function of the wing lift, and the wake dimensions are functions of the profile drag and essentially independent of the lift.

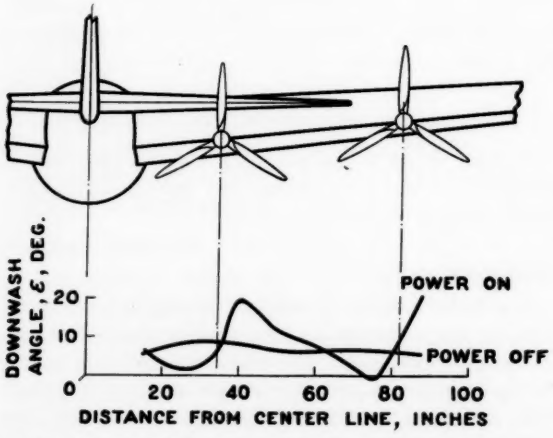

FIG. 12. Variation of power-off downwash angles across the elevator hinge line. Four-engine pusher airplane. Power off: α_i, 10.2°, C_L, 1.08. Power on: α_i, 10.2°, C_L, 1.12°, T_{C_0}', 0.205.

The location of the wake behind a wing coincides with that of the trailing vortex sheet. This coincidence enables the charts of vortex sheet displacement[2] also to be used to locate the wake. These charts show the value of the wake displacement,

$$h = \int_{T.E}^{x} \tan \epsilon \, dx$$

as a function of the wing shape, the flap condition, and the distance behind the wake origin. A discussion is also given[1] of the origin of the wake for the case of flapped and stalled wings.

The wake may be completely described by its width, the loss in dynamic pressure at the wake center, and the shape of the wake profile. The fact that the profile drag of an airfoil section may be equated to the momentum loss in the wake has enabled these wake dimensions to be expressed in terms of the profile-drag coefficient and the distance behind the airfoils. Empirical expressions have been derived for the wake dimensions, which are as follows:

$$\eta = \frac{2.42\, c_{d_0}^{1/2}}{\xi + 0.3}$$

and $$\zeta = 0.68\, c_{d_0}^{1/2}\, (\chi\iota + 0.15)^{1/2}$$

in which

η = $\dfrac{\text{loss in dynamic pressure at wake center}}{\text{free stream dynamic pressure}}$.

ζ = $\dfrac{1}{2}\left(\dfrac{\text{wake width}}{\text{wing chord}}\right)$.

ξ = $\dfrac{\text{distance behind trailing edge of wing}}{\text{wing chord}}$.

c_{d_0} = section profile-drag coefficient.

A plot of the wake width, 2ζ, for various values of c_{d_0} is given in Fig. 13 against distance behind the trailing edge of the airfoil.

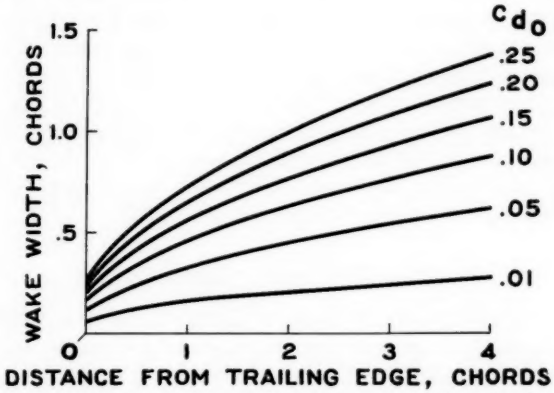

FIG. 13. Wake width against distance from trailing edge for different profile-drag coefficients. $2\xi = 1.36 c_{d_0}^{1/2}(\zeta + 0.15)^{1/2}$.

The foregoing equations also apply with considerable accuracy even for the case of stalled wings. The large increase in the wake width when the wing stalls, corresponding to the increase in c_{d_0}, is shown by comparison of the contour maps for the unstalled and stalled cases of Figs. 14 and 15.

Fuselage Boundary Layer

The boundary layer thickness at the rear of the fuselage and the average decrease in dynamic pressure within the boundary layer are dependent on the profile drag of the fuselage. If the turbulent boundary layer profile is assumed to be of the form $u/u_0 = (y/\delta)^{1/7}$ in which u is the local velocity, u_0 is the velocity at the edge of the boundary layer, y is the distance from the fuselage surface, and δ is the width of the boundary layer, the boundary layer width at the tail of the fuselage has been derived from the momentum integral, as

$$\delta = 1.63 \sqrt{C_D \times S}$$

in which C_D is the drag coefficient of the fuselage based on the area S. The average deficiency in dynamic pressure in the boundary layer Δq is given approximately by,

$$\Delta q = 0.22 q_0$$

The results of several experimental investigations are in practical agreement with the theory (references 3 and 8).

The equations apply, however, only for this case of a fuselage at a low angle of attack. The contours of dynamic pressure in the boundary layer of a fuselage at a low and a high angle of attack are shown in Fig. 16. At the higher angles, the boundary layer is displaced upward and its effect is felt more strongly by the vertical tail than by the horizontal one.

Although several tests made with fuselage-tail combinations[3] indicate that the horizontal tail effectiveness may be decreased from 5 to 10 percent by the fuselage boundary layer, it is believed that the effect is much smaller with well-shaped fuselages and high-aspect-ratio tails.

Slipstream Velocity

In the determination of the effects of the propeller on the tail, it is necessary to know the magnitude and the distribution of velocity in the propeller slipstream as a

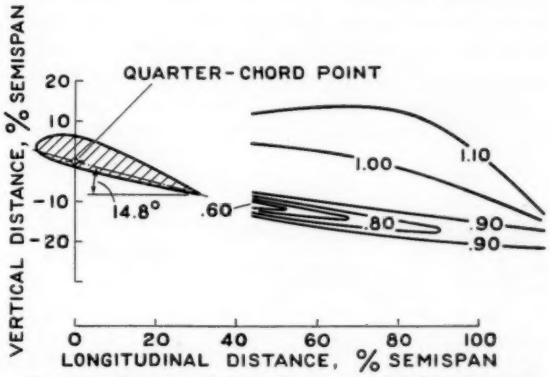

FIG. 14. Contours of dynamic pressure (q/q_0) in the wake behind an airfoil. U.S.A. 45 tapered airfoil, $\alpha = 14.8°$, C_L, 1.35.

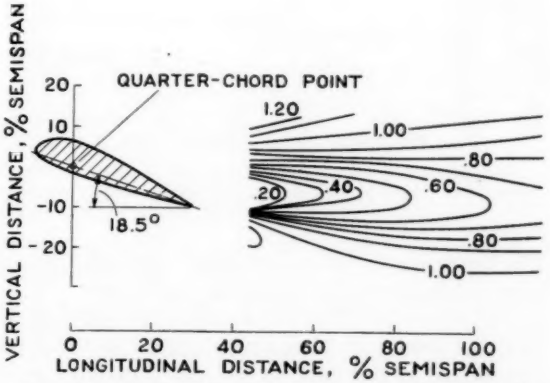

FIG. 15. Dynamic-pressure (q/q_0) contours in the wake behind a stalled wing. U.S.A. 45 tapered airfoil, $\alpha = 18.5°$; C_L, 1.00.

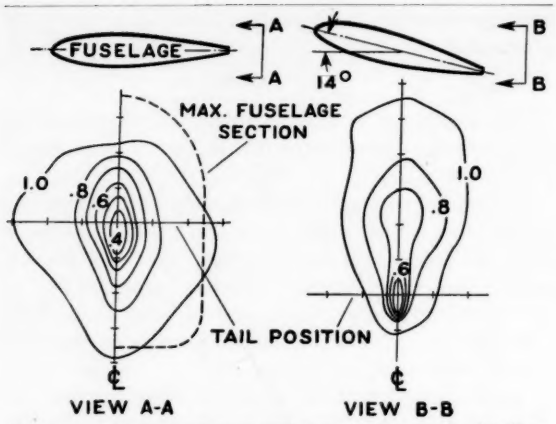

FIG. 16. Dynamic-pressure contours at the rear of a fuselage, α, 0° and 14°.

function of the propeller operating conditions and the airplane arrangement. The variables are numerous and the discussion must be based to a large extent on experiments. Measurements of the dynamic pressure in the slipstream have been made for a number of airplanes. Figs. 8 and 9 show typical power-off and power-on dynamic pressure contours for a single-engine, high-wing monoplane, and Figs. 10 and 11 show similar results for a 4-engine midwing monoplane with pusher propeller. A cross-plot of the distribution of the dynamic pressure at the elevator hinge line for the four-engine airplane, showing the effect of the slipstream on the dynamic pressure at the tail, is shown in Fig. 17.

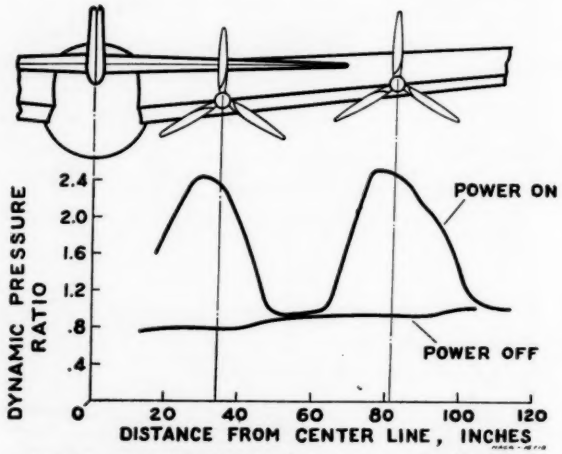

FIG. 17. Variation of dynamic-pressure across the elevator hinge line. Four-engine pusher airplane. Power off: α_t, 10.2°; C_L, 1.08. Power on: α_t, 10.2°; C_L, 1.12; Tc_0', 0.205.

The thrust coefficient and the angle of attack represent most nearly the power-on landing conditions.

The slipstream diameter is about the same as the propeller diameter; however, at large angles of attack, the outline is distorted due to the cross-flows in the vortex sheet (Fig. 11). Since the propeller thrust is equal to the momentum imparted to the slipstream, the average slipstream velocity may be theoretically expressed in terms of the propeller thrust, as

$$V_s/V = \sqrt{1 + (8/\pi)T_c}$$

in which V_s is the slipstream velocity and T_c = thrust/$\rho V^2 D^2$.

Close agreement has been shown between calculations of the momentum imparted to the slipstream based on measurements of the dynamic pressure in the slipstream and the experimental propeller thrust. It may be shown that

$$T = \pi q_0 \int_0^R r\left(\frac{q}{q_0} - \sqrt{\frac{q}{q_0}}\right)dr$$

in which R is the propeller radius, q is a dynamic pressure at a radius r from the center of the propeller, and q_0 is the free-stream dynamic pressure. The integration is performed graphically and, in four of the six cases investigated, the integrated values were within 5 percent of the experimental. The two other integrated values differed by 13 and 21 percent from the experimental values. The average value of the slipstream velocity may therefore be calculated with considerable accuracy from the value of T_c of the propeller, and the slipstream distribution may be approximated by reference to charts such as Fig. 17.

PREDICTIONS OF TAIL CHARACTERISTICS

It is next necessary to show how the knowledge of the variables determining the tail performance enables the tail characteristics to be predicted. The following method is suggested. Construct charts of the resultant down-wash angles and dynamic-pressure distribution across the span of the tail by superposition of the flows from the wing, the fuselage, and the propeller. These charts will be similar to those of Figs. 12 and 17. For some flight conditions perhaps only the fuselage boundary layer will change the dynamic pressure at the tail, whereas in others the effects of the flows from the wing, the fuselage, and the propeller will occur together.

The normal-force coefficient of the tail on the airplane may then be expressed as

$$C_{N_t}' = K(\bar{q}/q_0)\,(dC_{N_t}/d\alpha_t)\,(\alpha_t - \bar{\epsilon})$$

in which

$$\bar{q} = (1/S_t)\int_{-b_t/2}^{b_t/2} cq\,dy; \quad \bar{\epsilon} = (1/\bar{q}S_t)\int_{-b_t/2}^{b_t/2} \epsilon cq\,dy$$

The terms $\bar{q}$ and $\bar{\epsilon}$ will be recognized as the weighted mean values of the dynamic pressure and the angle at the tail, respectively. The values of $dC_{N_t}/d\alpha_t$ may be taken from charts for the tail alone, such as Fig. 1; α_t is the geometrical angle of the tail setting with reference to the relative wind; and q_0 is the dynamic pressure corresponding to the flight speed. The factor K is added to take into account effects due to the

limited immersion of the tail in the slipstream or wake and to the finite boundaries of these flows.

The value of the factor K, although it has been the subject of extensive theoretical and experimental research, is still not well known. For the best case of a relatively small tail immersed in a uniform slipstream of larger dimension, it may approach the value of 1. Experiments on two airplanes in the N.A.C.A. full-scale wind tunnel in which the tail was largely immersed in a slipstream gave values of $K = 0.94$ and 0.78.

In the case of the four-engine airplane in which the distribution of q and ϵ across the span of the tail was very irregular (Figs. 12 and 17), the value of K decreased to about 0.58. Results obtained on other airplanes with slipstreams varied between these limits. In the case of a wake or a boundary layer, the value of K may be greater than unity although, for wakes of substantial width, the value of $K = 1$ is quite accurate. The evaluation of K as a function of the distribution of dynamic pressure and angle across the tail, and as a function of the relative tail and slipstream or wake size, remains as one of the most important subjects for further research.

After evaluation of K, the elevator effectiveness, the elevator hinge moments, etc., may be obtained for any flight condition, as

$$(dC_{N_t}/d\delta_e)' = K(\bar{q}/q_0)dC_{N_t}/d\delta_e$$
$$(dC_{h_e}/d\delta_e)' = K(\bar{q}/q_0)dC_{h_e}/d\delta_e$$

The primed values are the characteristics of the tail as mounted on the airplane. The foregoing expressions have been shown to be in excellent agreement with experimental results.

To take into account effects due to the arrangement of the tail on the airplane, it is desirable, when the stabilizer is mounted high on the fin, to integrate for $\bar{q}$ and $\bar{\epsilon}$ only over the exposed surface. When the tail passes through the center of the fuselage, the integration should be extended through.

References

[1] Silverstein, Abe, Katzoff, S., and Bullivant, W. Kenneth, *Downwash and Wake behind Plain and Flapped Airfoils*, N.A.C.A. Technical Report No. 652, 1939.

[2] Silverstein, Abe, and Katzoff, S., *Design Charts for Predicting the Downwash and Wake behind Plain and Flapped Wings*, N.A.C.A. Technical Report No. 648, 1939.

[3] Gorsky, W. P., *Aerodynamic Investigation of Tailplanes with Balanced and Unbalanced Elevators*, Transactions of the Central Aero-Hydrodynamic Institute, No. 49 (Moscow), 1930.

[4] White, James A., and Hood, Manley J., *Wing-Fuselage Interference, Tail Buffeting, and Air Flow about the Tail of a Low-Wing Monoplane*, N.A.C.A. Technical Report No. 482, 1934.

[5] Glauert, H., *Airplane Propellers*, Vol. IV, Div. L, Sec. 6, *Downwash behind a Propeller*, Aerodynamic Theory, W. F. Durand, ed., Julius Springer (Berlin), 1935, page 165.

[6] Ferrari, C., *Some Experiments on the Slipstream Effect*, N.A.C.A. Technical Memorandum No. 820, 1937.

[7] Stüper, J., *Effect of Propeller Slipstream on Wing and Tail*, N.A.C.A. Technical Memorandum No. 874, 1938.

[8] Freeman, Hugh B., *Measurements of Flow in the Boundary Layer of a 1/40-scale model of the U.S. Airship "Akron,"* N.A.C.A. Technical Report No. 430, 1932.

Necrology

Harvey Clyde Mummert

Harvey Clyde Mummert, an Associate Fellow of the Institute, died on May 3, 1939, at his home in Bath, N.Y., at the age of 47.

Mr. Mummert was Vice-President and Chief Engineer of the Mercury Aircraft Company of Hammondsport. Formerly an engineer with the Curtiss Aeroplane and Motor Corporation, he was the designer of a number of famous airplanes. He held a transport pilot rating and took part in many national air races. He won Dayton Bicycle Club and Engineer's Club of Dayton trophies. In 1927 he placed third in the National Air Tour of 4000 miles for the Edsel Ford Trophy. Mr. Mummert attended The Case School of Applied Science, receiving a Bachelor of Science degree in 1914.

Joseph Edmund Woodman

Dr. Joseph Edmund Woodman, an Associate Fellow of the Institute, died on May 19, 1939, at his home in New York.

Dr. Woodman was Professor Emeritus of Geology at New York University. Besides being prominent in the field of geology he was the author of several articles on aeronautical meteorology. He was Lecturer on Aeronautical Meteorology at New York University from 1926 to 1938 and Director of the Meteorological Observatory at that institution from 1935 to 1938. From 1936 to 1938, he was a member of the Executive Committee and Chairman of the Operations Committee of the Whiteface Meteorological Observatory.

Dr. Woodman was born on July 4, 1873, in Newbury, Massachusetts. He attended Harvard University, receiving Sc.B., A.M., and Sc.D. degrees, the latter in 1902.

In addition to his affiliation with the Institute Dr. Woodman was a member of the American Meteorological Society and a Fellow of the Geological Society of America.

Poppet Valve Dynamics

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AND

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ABSTRACT

Measurements of the motion of a pushrod-operated poppet valve at normal operating speed showed considerable deviation from the motion at low speed. Jumping was observed at a speed very much lower than the speed which would be predicted by the usual analysis. The observed discrepancy is attributed to flexibility in the operating mechanism. A mathematical analysis is presented which takes account of flexibility and gives a reasonable check on the observed motion. The effect of speed, valve spring pressure and cam form was investigated by means of a mechanical model. Special cam forms for eliminating jumping at a single speed are suggested.

THE lift curve of a poppet valve in operation is usually assumed to be identical with the lift curve at a very low speed. Few actual measurements of lift curves under operating conditions have been published; among these was an article written in 1929 by Jehle and Spiller.[1] In this article, the authors dealt mainly with the effect of cam form on valve spring vibration, mentioning the rigidity of the parts of the valve gear as a contributing cause of faulty action, but offering no computations to show the effect of this variable.

The experiments and analysis presented herein are for the purpose of supplying this deficiency in the literature on poppet valve mechanisms. The result of flexibility in the valve operating mechanism is to cause the valve motion to differ from that prescribed by the cam. In such cases the actual valve lift curve determines the motion of the springs, and so its harmonic components, and not those determined from the cam form are significant for spring surge predictions. Along with the effect on spring surge, flexibility may give rise to unexpectedly high stresses in the valve gear, with consequent pounding out of valve seats, distortion or fracture of valve stems and heads, and pitting or battering of cams and cam followers. In addition to these mechanical difficulties, the change in lift may cause a change in breathing capacity with a consequent change in output.

EXPERIMENTAL PROCEDURE

The valve gear of a dummy engine with pistons, rods, and extraneous parts removed, was arranged to be operated by an electric motor. Measurements of valve position were made by a telescope equipped with a crosshair and micrometer adjustment as shown in Fig. 1. This illustration also shows the means for stroboscopic illumination, controlled by a movable contact on the crankshaft. For each measurement, the contact was

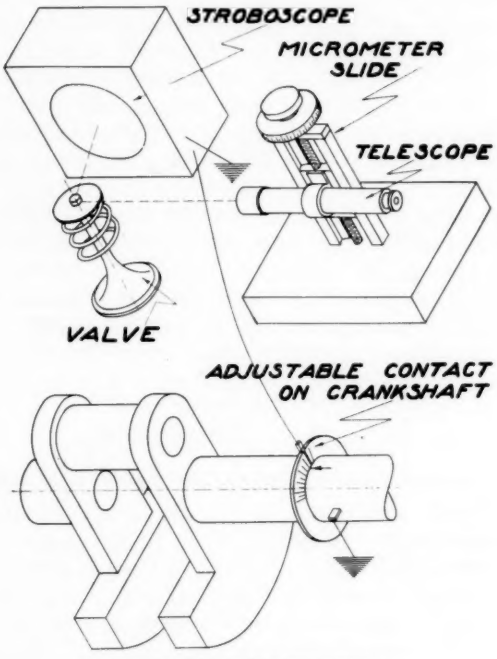

FIG. 1. Measuring apparatus.

set to flash the stroboscope at an arbitrary crank angle while the corresponding position of the valve was observed through the telescope. Valve lift curves determined from these measurements, both with and without gas pressure loading on the valve, are presented in Figs. 8 and 9. Note in Fig. 8 the appearance of jumping at a speed very much lower than the normal operating speed (1900 r.p.m.). By comparing the measurements with a relatively simple mathematical analysis, it was found that the valve motion could be predicted with reasonable accuracy. In addition, the analysis gives an understanding of the basic nature of the problem.

ANALYSIS

The valve gear system of the engine used is shown diagrammatically in Fig. 2a. An exact analytic solution for the vibration frequencies could be found, but the method is too laborious to justify the increase in precision, since the check between experimental values and

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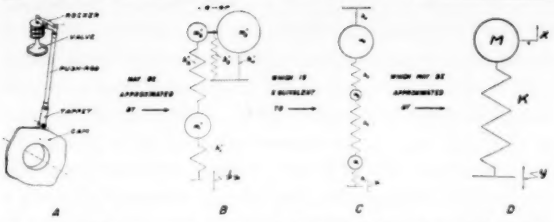


FIG. 2. Valve mechanism and approximately equivalent systems.

those computed by the following simplified analysis is satisfactory. Fig. 2 shows the successive steps by which the final approximately equivalent system (Fig. 2d) was found. To obtain the system of Fig. 2b from the actual system, it is necessary to assume that the actual system is equivalent to one made up of concentrated masses connected by flexible members shown as springs.

In Fig. 2b,

k'_1 is the stiffness of the cam;
k'_2 is the stiffness of the push-rod;
k'_3 is the stiffness of the rocker arm, rocker box, and bearings;
k'_4 is the stiffness of the valve springs;
r is the rocker ratio;
m'_1 is the sum of the masses of the cam follower assembly and half the push-rod;
m'_2 is the sum of the mass of the other half of the push-rod and the push-rod end mass of the equivalent system substituted for the rocker arm;
m'_3 is the sum of the masses of the valve end of this same system, the valve-springs retainer and locks, the valve, and one-third of the valve springs.

The system of Fig. 2c is exactly equivalent to that of Fig. 2b when:

$$k_1 = k'_1/r^2 \qquad m_1 = m'_1/r^2$$
$$k_2 = k'_2/r^2 \qquad m_2 = m'_2/r^2$$
$$k_3 = k'_3 \qquad m_3 = m'_3$$
$$k_4 = k'_4$$

The spring constants k_1, k_2, k_3, k_4 were determined by measuring the deflections at various points in the gear resulting from a static load on the valve. As a check, separate members of the valve mechanism were loaded and their stiffnesses determined. The masses equivalent to the rocker arm were found from its dimensions and its experimentally determined moment of inertia; the other masses were measured directly.

The equations of motion for the three masses of Fig. 2c are:

$$\begin{aligned} m_1\ddot{x}_1 + k_1(x_1 - y_c) + k_2(x_1 - x_2) &= 0 \\ m_2\ddot{x}_2 + k_2(x_2 - x_1) + k_3(x_2 - x_3) &= 0 \\ m_3\ddot{x}_3 + k_3(x_3 - x_2) + k_4x_3 &= 0 \end{aligned} \qquad (1)$$

and the resulting frequency equation[2] is the cubic in ω^2:

$$\omega^6 - \omega^4\left(\frac{k_1 + k_2}{m_1} + \frac{k_2 + k_3}{m_2} + \frac{k_3 + k_4}{m_3}\right) + \omega^2\left(\frac{k_1k_2 + k_3(k_1 + k_2)}{m_1m_2} + \frac{k_3k_4 + k_2(k_3 + k_4)}{m_2m_3} + \frac{(k_1 + k_2)(k_3 + k_4)}{m_3m_1}\right) - \frac{k_1k_2k_3 + k_2k_3k_4 + k_3k_4k_1 + k_4k_1k_2}{m_1m_2m_3} = 0 \qquad (2)$$

Substituting the values of k_1, k_2, k_3, k_4, m_1, m_2, m_3 the roots of this equation are:

$\omega_1 = 1610$ radians per sec.
$\omega_2 = 7370$ radians per sec.
$\omega_3 = 15{,}310$ radians per sec.

Inasmuch as there was no experimental evidence of any but the low frequency, further simplification to a vibrating system of one degree of freedom, as illustrated in Fig. 2d is justifiable. In determining the constants K and M from k_1, k_2, k_3, k_4, and m_1, m_2, m_3, judgment must be exercised in order that the simplified system will approximate the actual system closely. For the particular system in question, the following relations were assumed:

$$K = k_4 + \frac{1}{1/k_1 + 1/k_2 + 1/k_3} \qquad (3)$$

$$M = m_2 + m_3 \qquad (4)$$

also

$$y = y_c\frac{1}{k_4(1/k_1 + 1/k_2 + 1/k_3) + 1} \qquad (5)$$

The proper choice of relationships depends upon the observed relative values of k_1, k_2, k_3, and k_4 and the relative values of m_1, m_2, and m_3. The resulting simplified system has a natural frequency $\omega_n = \sqrt{K/M}$ of 1560 radians per sec. which is within 2 percent of the lowest frequency of the more complicated case, indicating that Eqs. (3) and (4) for determining K and M were properly chosen.

While an analytical solution of the problem is possible, it was found that graphical integration was no more difficult. In addition, the graphical solution gives a valuable illustration of the physical processes involved.

The equation of motion of a vibrating system similar to Fig. 2d is,

$$\ddot{x} = \omega_n^2\,(y - x) \qquad (6)$$

where $\omega_n^2 = K/M$.

Integrating once with respect to time and setting the crank angle $\theta = \omega_c t$, Eq. (6) becomes

$$\frac{\dot{x}}{\omega_c} = \frac{dx}{d\theta} = \left(\frac{\omega_n}{\omega_c}\right)^2\int_0^\theta (y - x)d\theta \qquad (7)$$

since y is a known function of θ, this equation may be integrated mechanically or graphically, step by step.

In order to perform the integration, it is necessary to know y as a function of crank angle and the initial conditions. It was observed that the valve was at rest on its seat after closing and remained steadily there until the beginning of the next cycle. This justifies treating each operation of the valve as a separate transient. Referring to Fig. 3 where x is the response curve, y the low speed curve, and y_c the projected cam curve, differing from y by the valve-gear compression under the valve-spring load, the integral on the right side of Eq. (7) will be seen to be the shaded area A_1. This

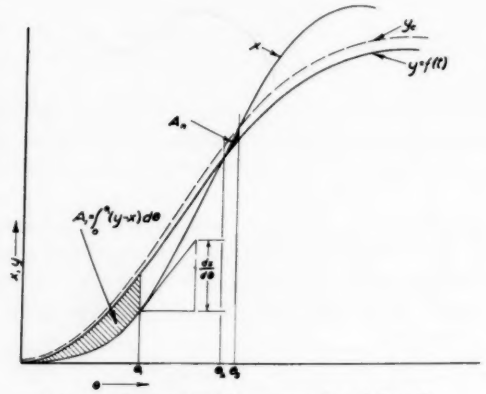


FIG. 3. Geometrical interpretation of Eq. (7).

area, and consequently the valve velocity, increases until $x = y$ at $\theta = \theta_2$. With a normal cam design, $dx/d\theta$ will exceed $dy/d\theta$ at this point, and there will be a tendency for the valve to leave the cam or jump. Jumping, which may be defined as the condition where there is no force between the cam follower and the cam, occurs because the normal valve gear is arranged so that only forces which cause compression in the mechanism are transmitted. Motion during jumping will be considered later.

For $\theta > \theta_2$ the shaded area, A_n, representing the increment to the integral of Eq. (7), becomes negative, and the valve velocity will therefore decrease. If ω_n^2/ω_c^2 is large the negative area may accumulate rapidly enough so that $dx/d\theta$ becomes equal to $dy/d\theta$ before x becomes equal to y_c, no jumping will occur as shown in Fig. 4 (dotted line) but transient vibration will persist as indicated. On the other hand if ω_n^2/ω_c^2 is small, the negative area, A_n, will not accumulate with sufficient rapidity and the valve will jump as indicated by the dashed line of Fig. 4. Thus a high ratio of natural frequency to crankshaft revolution speed is desirable in order to reduce the severity of jumping.

If the mass of the valve gear is decreased, or if both the valve spring and valve gear stiffnesses are increased proportionally, the rotative speed for a given valve motion will be increased, and the jumping speed may be removed from the operating range. In cases where it is impractical to do this, the cam form may be modified to give proper operation at a single speed. Two possibilities for this are seen in Fig. 5. These lift curves have in common a sharp increase in velocity during the initial rise, which is believed to be characteristic of any cam designed with this end in view. Lift curves for cams of this sort may be predicted by integration of Eq. (7).

In addition, Eq. (5) may be extended to cover the effect of external loads such as gas pressure by the addition of another term, giving

$$M\ddot{x} + K(x - y) = F(t) \tag{8}$$

where $F(t)$ is the gas force on the valve.

Motion During Jumping

When the force in the valve mechanism becomes zero, the motion of the valve ceases to be influenced by the cam. The resulting freely vibrating system may also

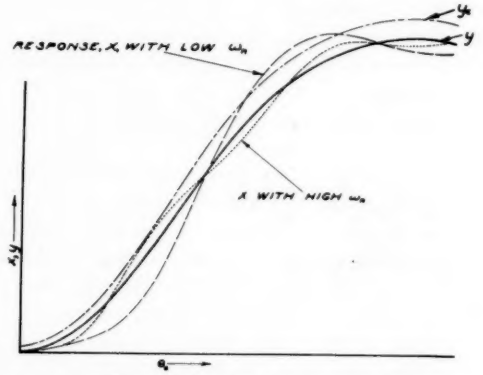
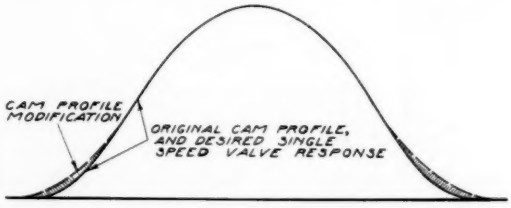


FIG. 4. Effect of changing the natural frequency of the valve mechanism.



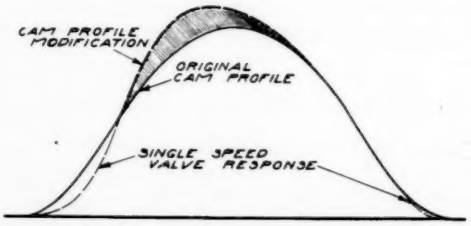


FIG. 5. Possible cam designs to give smooth valve action at a single speed.

be approximated by one having a single degree of freedom, in this case, with a stiffness equal to that of the valve spring itself and a mass equal to the sum $m_1 + m_2 + m_3$ (see Fig. 2c). Since the system is completely altered when jumping occurs, a new solution must be used.

Since the spring load for both the valve open and the valve closed positions may be found, and the lift between these two is known; by simple proportion, the position of the axis of zero spring force may be calculated. During jumping the motion of the valve is simple harmonic about the axis of zero spring force with the initial position and velocity given by the values of these quantities at the instant the pushrod force becomes zero as determined from previous analysis, and proceeding with a frequency

$$\omega_v^2 = k_4/(m_1 + m_2 + m_3) \qquad (9)$$

until the next contact between the cam and cam follower. This type of motion is shown in Fig. 6.

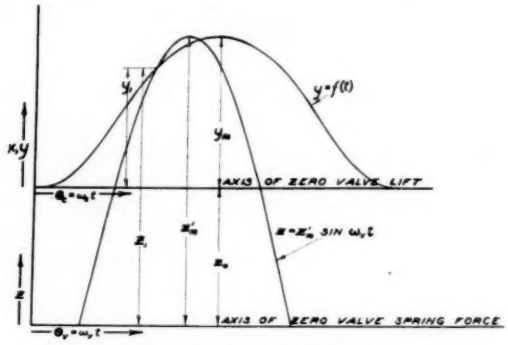


FIG. 6. Motion during jumping.

A complete curve computed according to the foregoing analysis is plotted with the corresponding measured lift curve in Fig. 7. While the agreement is by no means perfect, the computed curve shows the same general characteristics as the measured one.

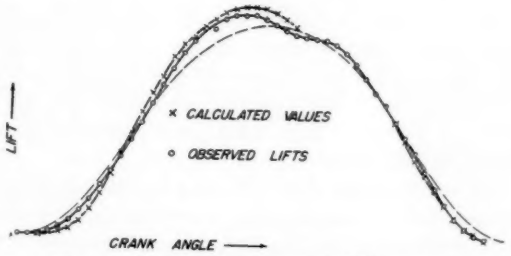


FIG. 7. Measured and computed lift curves.

At first, it was thought that motion of the cylinder head itself might be at least partly responsible for the difference between the observed and calculated values, but measurement by means of the M.I.T.-Sperry vibration equipment showed this motion to be negligible. However, stroboscopic observation of the cam revealed torsional vibration, the amplitude of which was $\pm 2°$ on a crank angle basis. This amplitude is sufficient to account for the observed discrepancy. In a more refined analysis, torsional motion of the cam would have to be taken into account. Such procedure, however, would introduce non-linear terms in the equation of motion and the resulting complication of the analysis would hardly be justified.

The effect of friction was not considered because it was small, indefinite, and possibly non-linear. Consequently the analysis cannot be expected to check the observations very far along the lift curve. However, making use of the observation that the transient had died out shortly after the maximum opening position, a new analysis was made from an arbitrary point on the closing side of the curve, the results of which are also plotted in Fig. 7. From the agreement here, the justification for the preceding analysis is quite apparent.

EXPERIMENTAL RESULTS

Fig. 8 shows the effect of speed upon the various irregularities of valve response. The most surprising

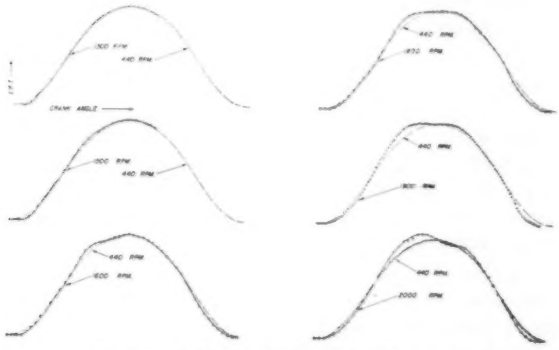


FIG. 8. Variation of lift curve with r.p.m.

effect is the failure of the observed valve opening lag to show the expected increase with speed, whereas the closing lead acts quite reasonably. This may be due possibly to the torsional motion of the camshaft. The slopes of the curves indicate that the maximum velocity during opening increases; at 1900 and 2000 r.p.m. it is some 15 percent greater than anticipated by the design. Perhaps more serious in its effects is the increase in closing velocity, which is 40 percent higher than expected at 2000 r.p.m. The early appearance of valve jumping, at 1500 r.p.m., and the development of this irregularity with speed are evident. The mass of the valve used in these tests was slightly greater than that of a standard valve, so that these speeds are approximately 100 r.p.m. lower than those at which the same phenomena would be observed in the actual engine.

For Fig. 9 the valve was loaded with steam, the pressure on the valve being recorded on the M.I.T. balanced pressure indicator[4] and transferred directly to the lift

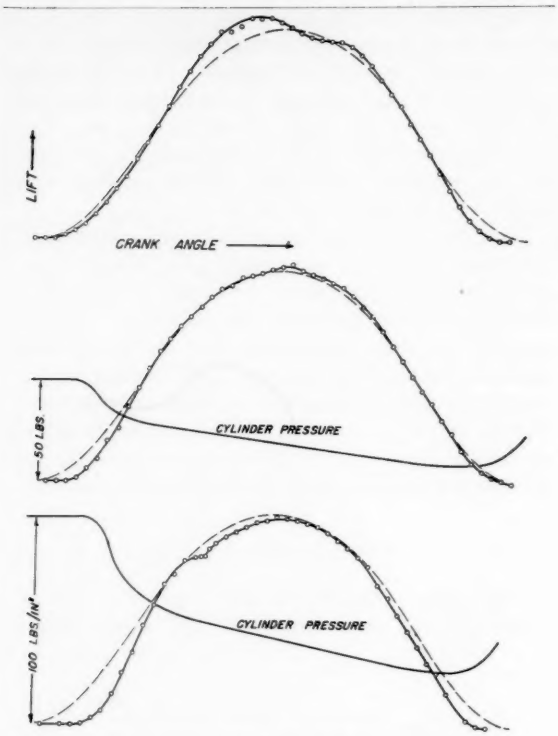


FIG. 9. Lift curves with gas loading (2000 r.p.m.).

curve plot. The exhaust pressure tends to compress the valve mechanism and thus helps to prevent jumping. This may explain the prevalence of certain failures in the inlet valve mechanism which seldom occur in the exhaust.

In this system, a 50 lb. per sq.in. cracking pressure increases the valve opening lag by 5°, and 100 lb. per sq.in. increases it by 15°. The pressure deflects the mechanism to such an extent that the effective valve opening area is appreciably reduced.

THE TORSIONAL ANALOGUE

In order to investigate the effect of a number of changes in the valve gear, a torsional analogue, shown diagrammatically in Fig. 10, was developed. This device eliminates the large amount of labor involved in analytical or graphical integration, is easily adjustable to simulate any valve gear conditions, has a cam which may be easily cut from a soft material, and operates at a low speed where pen recording is possible.

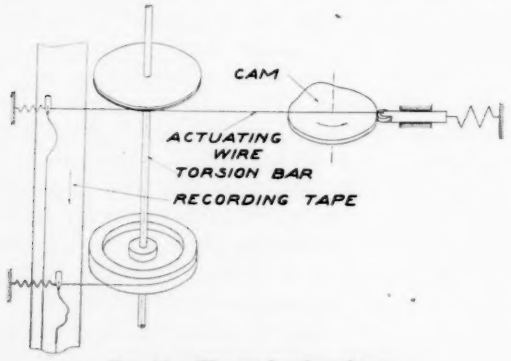


FIG. 10. The torsional analogue.

Results obtained from the torsional analogue show the same characteristics as those obtained from the actual valve gear. (Compare Fig. 11 with Fig. 8; also compare with reference (1).) This indicates that the assumptions of the analysis are valid since the analogue was arranged to simulate the simplified system, not the actual valve gear.

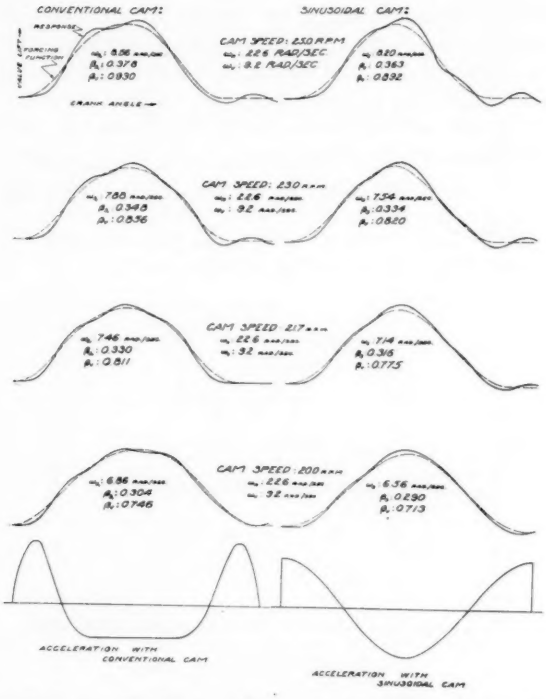


FIG. 11. Torsional analogue "valve lift" curves. An analysis of a single mode, non-linear vibrating system. The effect of speed, with both cams.

Fig. 11 shows the effect of speed with both cam designs tested—the conventional cam previously used in the engine, and a pure sinusoidal cam having the same lift and timing. These cams differ widely, yet the behavior of the valve gear is not greatly affected by the change in cam form.

Fig. 12 shows the effect of changing the valve spring tension, and of increasing the natural frequency of the valve system. Increasing the natural frequency of the system some 30 percent with no other change is seen to improve the valve response materially.

Fig. 13 is identical with Fig. 12 except that the cam design is sinusoidal rather than conventional.

CONCLUSIONS

(1) When operating at its designed speed, the mo-

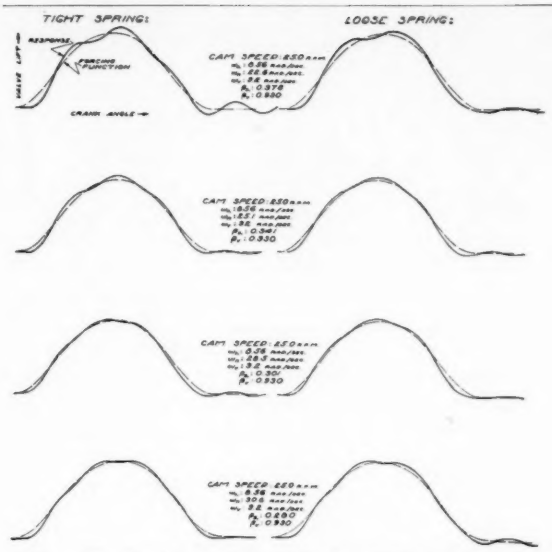


FIG. 12. Torsional analogue "valve lift" curves. The effect of valve spring tension and of natural frequency with the conventional cam, at constant speed.

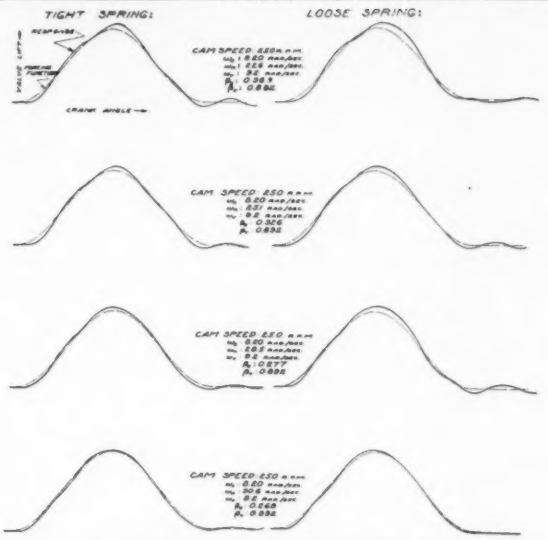


FIG. 13. Torsional analogue "valve lift" curves. The effect of valve spring tension and of natural frequency with the sinusoidal cam, at constant speed.

tion of a conventional pushrod-operated valve differed considerably from its motion at low speed.

(2) The difference in motion is attributed to flexibility in the operating mechanism.

(3) Jumping occurred at a much lower speed than anticipated from the usual computations which assume a rigid operating mechanism.

(4) It is possible to predict the motion at high speed with reasonable accuracy by a consideration of the valve gear as a vibrating system with one degree of freedom.

(5) Improved operation of such a valve gear may be obtained by increasing its natural frequency, either by reducing the mass of the valve and its associated parts or by increasing the stiffness of the operating mechanism.

(6) Improved operation may also be obtained by the use of stiffer valve springs although this method is not as effective as (5).

(7) Wide variation in cam form such as between a conventional cam and a sinusoidal cam apparently cause little change in the observed effects.

(8) Special cams may be designed to give proper functioning of the valve gear without jumping *at a single speed*.

Although experiments were made only on a conventional pushrod operated, overhead valve gear of a radial aircraft engine, there is no apparent reason why the principles outlined should not be applicable, with appropriate modifications, to any poppet valve mechanism.

REFERENCES

[1] Jehle, Ferdinand, and Spiller, W. R., *Idiosyncrasies of Valve Mechanisms and Their Causes*, S.A.E. Journal, Vol. 24, pages 133–143, February, 1929.

[2] den Hartog, J. P., *Mechanical Vibrations*, pages 88–90, Chapter III, McGraw-Hill, New York, 1934.

[3] Draper, C. S., Bentley, G. P., and Willis, H. H., *The M.I.T.-Sperry Apparatus for Measuring Vibration*, Journal of the Aeronautical Sciences, Vol. 4, No. 7, pages 261–285, May, 1937.

[4] Taylor, E. S., antl Draper, C. S., *A New Engine Indicator*, Mechanical Engineering, March, 1933.

The Growth of the Circulation of an Airfoil Flying through a Gust

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AND

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THE rate of increase of the circulation about the tip of a wing flying through a vertical gust has recently been determined experimentally by Kuethe.[1] In the present paper, the results of these experiments are compared with the results of calculations based on the theories of von Kármán and Sears[2] and R. T. Jones.[3] The comparison of the experimental results with the former theory, carried out in reference (1), was in error. While the conclusions given there are not changed, it is considered advisable to correct the comparison with theory, and, further, to show a comparison with the Jones theory.

The Theoretical Circulation Due to a Sharp-Edged Gust

von Kármán and Sears have calculated the lift on an airfoil of infinite span during and following its entrance into the boundary of a sharp-edged vertical gust. The corresponding growth of the circulation about the airfoil was calculated in reference (1) by subtracting the "apparent mass lift" from the v. Kármán-Sears curve and dividing the remainder by the velocity of flight and the fluid density. This procedure assumes that all of the lift which arises from the circulation is given by the Kutta-Joukowski formula $L = \rho U\Gamma$, where L is the lift per unit span, ρ the density, U the velocity, and Γ the total circulation about the airfoil. That this assumption is not valid when the circulation is variable can be seen from the general expression for the lift in terms of the circulation Γ and its distribution across the chord, $\gamma(x)$*

$$L(t) = -\rho \frac{d}{dt} \int_{-1}^{1} \gamma(x)x\,dx + \rho d\Gamma/dt + \rho U\Gamma \quad (1)$$

In this expression the "apparent mass lift" is included in the first term; the assumption made in reference (1) causes part of this term and all of the second term to be neglected.

Although $L(t)$ is known, the circulation could be determined from Eq. (1) only by determining the distribution $\gamma(x)$ across the chord and then solving the equation as a differential equation for $\Gamma(t)$. It is easier to use the curve given by Wagner[4] for the circulation of an infinite wing following a sudden unit change of its angle of attack or velocity and to calculate $\Gamma(t)$ for the sharp-edged gust by the method used in reference (2) for the corresponding lift. Denoting Wagner's curve for a unit change of angle of attack (as reproduced in reference (3), Fig. 7, but considered as a function of the time rather than of the distance) by $F(t)$, the circulation function for the unit sharp gust is

$$\Gamma_1(t) = \frac{1}{2\pi} \int_0^t \Gamma_0'(\tau) F(t - \tau) d\tau \quad (2)$$

where $\Gamma_0(t)/2\pi$ is the ratio of the "quasi-steady" circulation (*i.e.*, the circulation which would be produced if there were no wake effects) in the sharp gust case to that in Wagner's case. From reference (2), Eq. (47), taking the airfoil chord equal to 2, this function is

$$\Gamma_0(t)/2\pi = (1/\pi)\left[\cos^{-1}(1 - Ut) - \sqrt{2Ut - U^2t^2}\right] \quad (3)$$

for $0 \leqq Ut \leqq 2$, and is equal to 1 for $Ut \geqq 2$. The calculation of Γ_1 has been carried out according to these equations, and the result is shown in Fig. 1 in the form of a ratio to its asymptotic value, which is equal to 2π. This ratio is called $R_1(t)$.

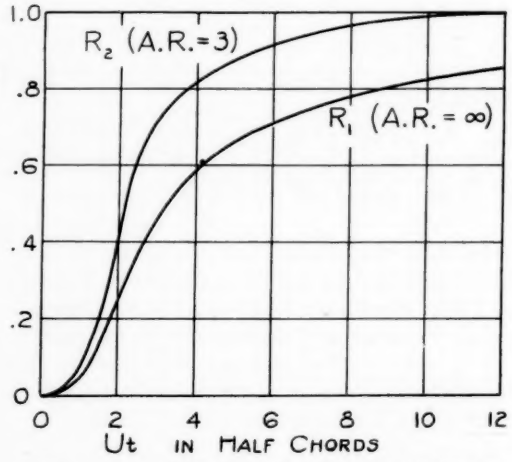

FIG. 1. The circulation about an airfoil during and following its entrance into a sharp-edged gust, for aspect ratios of 3 and ∞. $R(t) = \Gamma_1(t)/\Gamma_1(\infty)$, where $\Gamma_1(t)$ is the momentary value of the circulation.

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* This expression is easily obtained from reference (2) by differentiating their Eq. (12) according to the rule stated in Eq. (15), retaining the term involving $f(1)$ which is not equal to zero in this case, and making use of the fact that $U\gamma(1) = -d\Gamma/dt$. (The variable t represents the time. The airfoil chord has been taken equal to 2.)

Since the wing used in the experiments reported in reference (1) had an aspect ratio of 3, it might be expected that the agreement of the experimental results with the two-dimensional theory would be poor. Jones[3] has obtained approximate curves for the circulation of finite wings following a sudden unit change of angle of attack. These are analogous to Wagner's curve which has been used above, and may be employed in analogous fashion if it is assumed that conditions at every section of a finite wing are two-dimensional. Jones considered both uniform and elliptical lift distributions across the span and found negligible differences in the circulation curves; hence, his curve for elliptic loading with aspect ratio = 3 [Fig. 7 of reference (3)] is applicable to Kuethe's wing, although the latter was rectangular in planform.

With these approximations the circulation of a wing of aspect ratio 3 during and following its entrance into a unit sharp-edged gust has been calculated from Eqs. (2) and (3), using Jones's curve instead of Wagner's for $F(t)$. The result is shown in Fig. 1 as a ratio to its final value, which is in this case approximately 3.77 according to the results of the Prandtl wing theory, assuming elliptic loading. This ratio is called $R_2(t)$.

The Theoretical Circulation Due to an Actual Gust

The circulation function for the case of a wing passing through a graded gust is obtained by means of the formula[5]

$$\Gamma(t) = \Gamma_1(t)W(0) + \int_0^t \Gamma_1(t-\tau)W'(\tau)d\tau \quad (4)$$

where $\Gamma_1(t)$ is the circulation due to a unit sharp-edged gust, $W(t)$ is the gust velocity profile considered as a function of the time, and $t = 0$ represents the instant at which the leading edge begins to penetrate the gust. Eq. (4) amounts to a superposition of the effects of a series of elemental sharp gusts $W'(\tau)d\tau$. If W_m is the maximum gust velocity and Γ_m is the steady-state value of the circulation produced by a uniform gust of strength W_m, Eq. (4) can be written in the form

$$\Gamma(t)/\Gamma_m = (1/W_m)[R(t)W(0) + \int_0^t R(t-\tau)W'(\tau)d\tau] \quad (5)$$

where $R(t) = \Gamma_1(t)/\Gamma_1(\infty)$

Eq. (5) has been evaluated, using the experimental gust function W/W_m of reference (1), as plotted in Fig. 2, and using both $R_1(t)$ and $R_2(t)$, from Fig. 1, for the function R. The results are shown in Fig. 3.

Comparison with Experimental Results

In Fig. 3 are also plotted Kuethe's experimental curves of $\Gamma(t)/\Gamma_m$, reproduced from reference (1), Fig. 13.* The experimental curve which attains the higher maximum value corresponds to measurements of the circulation at a section $^7/_{30}$ths of the chord inboard from the tip; the other to measurements at a point $^1/_6$th of the chord inboard. For both experimental curves, the values of Γ_m were taken from theoretical span lift grading curves for a section $^1/_5$th of the chord inboard of the tip. It is seen that the measured circulation grows less rapidly than is predicted on the basis of Jones's approximate theory, but is in fairly good agreement with the v. Kármán-Sears two-dimensional theory. There are two circumstances which would tend to explain the disagreement between the experiments and Jones's theory. These are: (1) Jones's theory is based on a lifting-line approximation which, it can be shown, causes the circulation to

* In reproducing the experimental curves, the time scale has been shifted 0.011 sec. to account for the fact that the circulation measured in the wake at a certain location corresponds to the circulation that existed on the wing when its trailing edge occupied that position. Since the abscissa in Fig. 3 corresponds to the leading edge position, a correction equal to the time taken to move one chord length (30 cm.) at 29 meters per sec. has been made.

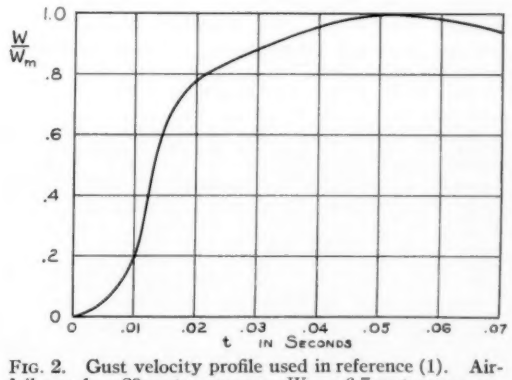

FIG. 2. Gust velocity profile used in reference (1). Airfoil speed = 29 meters per sec., W_m = 6.7 meters per sec.

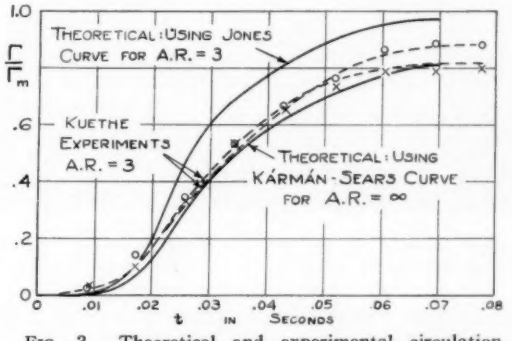

FIG. 3. Theoretical and experimental circulation curves for the gust of Fig. 2. Γ_m = steady-state circulation due to a uniform gust velocity of 6.7 meters per sec.

be overestimated for small values of t; and (2) a consideration of the sources of error in the experimental results indicates that the errors tending to decrease the measured circulation probably predominate. It seems unlikely however that these two effects would suffice to close completely the gap between the measurements and Jones's theoretical curve as shown in Fig. 3 for aspect ratio 3.

REFERENCES

[1] Kuethe, A. M., *Circulation Measurements about the Tip of an Airfoil during Flight through a Gust*, N.A.C.A. Technical Note No. 685, 1939.

[2] von Kármán, Th., and Sears, W. R., *Airfoil Theory for Non-Uniform Motion*, Journal of the Aeronautical Sciences, Vol. 5, No. 10, August, 1938.

[3] Jones, Robert T., *The Unsteady Lift of a Finite Wing*, N.A.C.A. Technical Note No. 682, 1939.

[4] Wagner, H., *Dynamischer Auftrieb von Tragflügeln*, Zeitschr. f. Angew. Math. u. Mech., Bd. 5, page 17, 1925.

[5] Jones, Robert T., *Calculation of the Motion of an Airplane under the Influence of Irregular Disturbances*, Journal of the Aeronautical Sciences, Vol. 3, No. 12, pages 419–425, October, 1936.

Book Reviews

Stephen Timoshenko, 60th Anniversary Volume; The MacMillan Company, New York, 1938; 277 pages, $5.00.

This volume comprises "Contributions to the Mechanics of Solids dedicated to Stephen Timoshenko by his friends on the occasion of his sixtieth anniversary." It will be welcomed by engineers for two reasons: First, it honors a great scientist and teacher, and, second, it presents many important contributions to the field in which Prof. Timoshenko is world renowned.

The book opens with a short biography of Prof. Timoshenko by Prof. John M. Lessells, Chairman of the committee in charge of publication, followed by a list of the books and technical articles he has written.

There follow 28 technical articles, by C. B. Biezeno and J. J. Koch, J. P. Den Hartog, L. H. Donnell, O. W. Ellis, Ludwig Föppl, J. N. Goodier, M. Hetényi, O. J. Horger, William Hovgaard, M. T. Huber, Lydik S. Jacobsen, G. B. Karelitz, Th. von Kármán, B. F. Langer, C. W. MacGregor, R. von Mises, A. Nadai, J. Ormondroyd, R. E. Peterson, L. Prandtl, C. Richard Soderberg, R. V. Southwell, G. I. Taylor, A. M. Wahl, E. O. Waters, Stewart Way, E. E. Weibel, and H. M. Westergaard.

These cover every phase of the Mechanics of Solids and will be valuable to specialists in that field. Many of them, particularly those on buckling and vibration problems, have direct application to airplane structures.

Cours Superieur de Pilotage aux Instruments, by M. POINTIS; Gauthier-Villars, Paris; 106 pages, 15 fr.

This explanation of instrument flying is very methodically done. It is profusely illustrated with small sketches showing the details of aircraft control in combination with the bank and turn indicator and other instruments.

The best feature of this book seems to be the logical arrangement of the material and the careful plan on which the book is built.

A great amount of practical advice is given the flyer. Following the theory under each section is practical advice, giving helpful suggestions to the student.

The first chapter explains how to coordinate movements to obtain perfection in the normal technique of flying.

The second chapter is devoted to blind flying or the use of instruments in blind flying, and this is subdivided into lateral and longitudinal stability. The third section under Chapter II gives the exercises necessary to fly blind, or in a cloud.

The fourth and last chapter is devoted to actual flight in the clouds giving the importance of fundamental exercises, and numerous suggestions on how this may be accomplished.

A. A. ILLYNE
Weems School of Navigation

Skycruiser, by HOWARD M. BRIER; Random House, New York, 1939; 238 pages, $2.00.

Here is a book any boy will enjoy reading. The author is a teacher of journalism at the University of Washington and the development of the story reflects his training as a newspaperman.

The book tells the story of a young test pilot who seeks adventure and finds it in a great flying boat—the largest ever built. All of the dare-devil experiences that a boy could expect from fiction will be found in its pages.

Improvements and Experience in Radio Soundings*

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A. H. MEARS AND C. HARMANTAS
U.S. Weather Bureau

ABSTRACT

Further improvements of the radio sonde developed at the National Bureau of Standards for the U. S. Navy Department are described. The improvements were directed to facilitate the mass production of the instrument while retaining its accuracy and simplicity. An analysis, based on data of the U.S. Weather Bureau, of the performance of the improved instrument in routine use at six Weather Bureau and one Navy Department aerological stations is presented. A quantitative evaluation of the accuracy of the radio sonde observations is included. The radio sonde system has provided a continuous sequence of upper-air observations to much greater heights and with greater regularity and reliability than the airplane method of sounding hitherto employed. Plans of the Weather Bureau and of the Navy Department call for routine use of the instrument described at about 35 aerological stations, during the fiscal year 1940.

I. INTRODUCTION

DURING the past year the radio sonde has been transformed from an experimental apparatus, requiring individual handling, into a commercial product, reasonably priced because of the application of mass production methods, and capable of meeting rigorous performance specifications under field operating conditions. Beginning June 1, 1938, the Navy Department inaugurated routine use of the radio sonde at Washington, D. C., and during July, 1938 the Weather Bureau began routine operation at Nashville, Tenn., Oklahoma City, Okla., Omaha, Neb., Oakland, Calif., Fargo, N. D., and Sault Ste. Marie, Mich.

Radio sonde service at two Navy Department shipboard stations was started in December, 1938. In addition, during April, May, and June, 1939, regular soundings were made from two ice-patrol cutters of the U.S. Coast Guard operating off the Newfoundland Banks. During the same period, regular soundings were made at Bermuda by the Massachusetts Institute of Technology in cooperation with Julien P. Friez & Sons Co., in connection with the hurricane research program of the Massachusetts Institute of Technology. All of these stations employed the Navy type radio sonde. In all, during the fiscal year 1939, some 3000 radio soundings were made in the regular course of collecting upper-air weather data. Present plans call for the routine use of this instrument at about 35 aerological stations during the fiscal year 1940.

The fundamental principles of the instrument employed have been described in two previous papers.[1] The present paper outlines the improvements effected in this instrument to facilitate its manufacture and to simplify the operating procedure required in its use. The engineering staff of Julien P. Friez & Sons Co. contributed materially to these improvements. Data on the performance of the improved radio sonde in routine use at seven stations are also presented. These data indicate the improvement in the regularity and range of the upper-air observations resulting from supplanting the airplane method of sounding by the radio sonde.[2]

II. TECHNICAL FEATURES OF THE IMPROVED INSTRUMENT

The essential components of the improved radio sonde are indicated in Fig. 1. The complete instrument ready for use is shown in the center. A light cardboard case, covered with a metallic foil and divided into two compartments, is employed. The front compartment houses the radio transmitter *a*, the plug-in battery

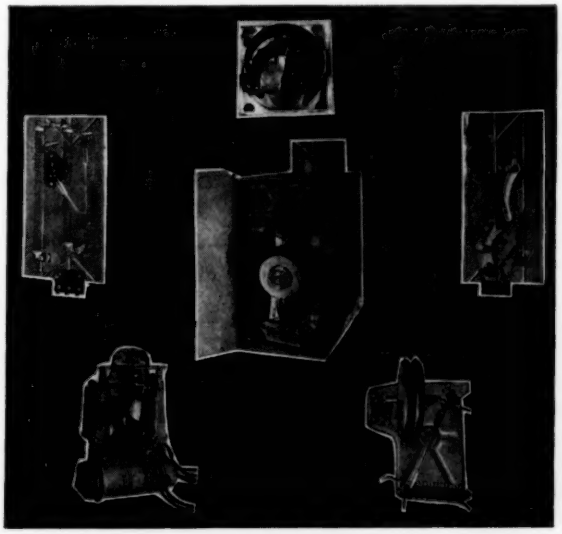

FIG. 1. Essential components of the radio sonde used at Weather Bureau and Navy Department aerological stations.

Presented at the Meteorology Division, Seventh Annual Meeting, I, Ae. S., January 26, 1939. Revised May 13, 1939.

* Publication approved by the Director of the National Bureau of Standards of the U.S. Department of Commerce.

unit *b*, and the pressure-switching unit *c*. The rear compartment supports the radiation shield *d*, consisting of two thin concentric aluminum tubes, the inner one of which supports a mounting plate for the temperature- and humidity-sensitive resistance elements. Front and rear views of the mounting plate assembly are shown at *e* and *f*, respectively. A protecting cover *g* is provided for the cam and wire-wound resistor whereas the temperature capillary tube and hair element are directly exposed to the flow of air as the balloon carries the instrument upward.

The one-tube radio transmitter used represents an advance both in simplicity and performance. Based on suggestions of RCA Radiotron Inc., the circuit arrangement was simplified to require two triode elements housed in the same glass envelope in place of the three electron tubes previously used. One of the triode elements serves as the ultra-high-frequency oscillator, operating at 65 megacycles per sec., and the other triode serves as the modulating oscillator. The latter oscillates at 1 megacycle per sec. in short pulses occurring at an audio-frequency rate which depends upon the time constant of the circuit containing the temperature- and humidity-sensitive resistors and hence upon the values of these resistors. The circuit arrangement is such that the ultra-high-frequency oscillator is interrupted during the short pulses of the modulating oscillator. The radio wave from the balloon transmitter is thus modulated at an audio rate which depends upon the value of the temperature or humidity resistor.

Besides the advantage of simplicity, the transmitting system provides much greater stability of the audio-frequency characteristic; *i.e.*, of the relation between the value of the audio frequency and the circuit resistance. The ground checks required prior to the release of a radio sonde are thus limited to the taking of surface pressure, temperature, and humidity observations.

An important feature of the instrument design is the complete thermal isolation provided for the temperature and humidity elements from the main radio sonde assembly. Only three wires connect the two units.

The two-compartment design shown in Fig. 1 was adopted after numerous ascension tests of a large number of case designs affording a variety of exposures of the sensitive elements. The temperature measurements obtained in the stratosphere indicated the importance of thermally isolating the temperature element from the remainder of the radio sonde. To serve as a standard of comparison, an assembly comprising two completely detached units (except for the connecting wires) was tried, the radiation shield assembly being suspended about 18 inches above the main portion of the radio sonde. This arrangement was found to give the coldest temperatures in the stratosphere. The case design shown in Fig. 1, although giving stratosphere temperature indications up to 1°C. warmer, was adopted for convenience in handling. The older balsa-wood case design employed previously gave stratosphere temperature indications up to 2°C. warmer.

III. Estimate of Absolute Accuracy of Radio Sonde Observations

In order to estimate the absolute accuracy of the observations obtained with radio sondes taken from stock and employed under field conditions, fifteen ascents were made at the National Bureau of Standards practically simultaneously with the routine early morning ascents at the Naval Air Station (10 miles away). In nine of the soundings, the balloon also carried a recording meteorograph so that, upon recovery, added checks on the accuracy of the radio sonde observations would be afforded. Six of the recording instruments were recovered, four providing suitable records for comparison. In five of the soundings at the National Bureau of Standards, practically complete observations were obtained during the descents as well as during the ascents. Two of the soundings, made a few hours apart, provided further data for comparison.

Additional data for estimating the absolute accuracy of the radio sonde temperature observations were obtained in a series of ascents at the U.S. Weather Bureau station at Omaha, Nebraska, in which recording meteorographs were carried by the balloon in the routine early morning radio soundings. Twenty of the recording instruments recovered provided suitable records for comparison with the radio sonde observations.

Still further data were obtained up to levels of about 5 kilometers by means of aerograph observations taken at the Naval Air Station once a week over a seven-month period from June through December, 1938. The aerograph ascents were made nearly simultaneously with the routine radio soundings, although adverse weather conditions resulted in time differences up to 3 hours in some 25 percent of the tests.

The results of the several temperature comparisons are summarized in Fig. 2. The comparisons were made at meteorologically significant levels except for the case of the comparison with the aerograph observations; in the latter case comparisons were made at 500-meter increments in altitude up to 5000 meters. The curves represent the total percentages of the radio sonde readings falling within specified deviations from the comparative observations.

In Fig. 2, curve (1) shows the results of the measurements at the National Bureau of Standards (independent of their comparison with the Naval Air Station observations). The results are based on ten tests, four of which involved direct checks of the radio sonde against recording meteorographs and six involving interchecks of the radio sonde data. Curves (2) and (3) show the results of the measurements at Omaha, Nebraska, representing twenty direct checks of the radio sonde against recording meteorographs. For

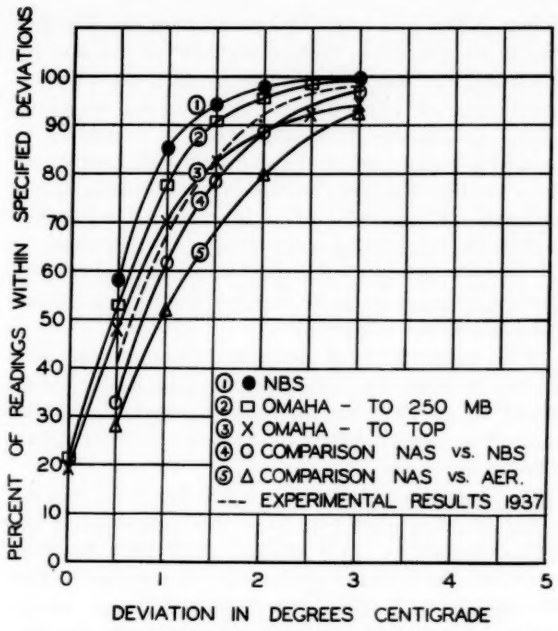
PERCENT OF READINGS WITHIN SPECIFIED DEVIATIONS
DEVIATION IN DEGREES CENTIGRADE
① ● NBS
② □ OMAHA - TO 250 MB
③ X OMAHA - TO TOP
④ O COMPARISON NAS vs. NBS
⑤ Δ COMPARISON NAS vs. AER.
--- EXPERIMENTAL RESULTS 1937

FIG. 2. Summary of comparative data forming basis for estimate of the absolute accuracy of the radio-sonde temperature observations.

curve (2), the observations were compared for levels up to 250 millibars (about 34,000 feet); for curve (3) all of the observations to the maximum heights reached by the balloon were compared. The reasons for this arbitrary division were: (a) the indicating accuracy of the system is not as good for temperatures lower than that obtaining at the 250-millibar level (about $-50°$C.) as it is for between $+30°$ and $-50°$C.; and (b), to provide for better comparison with the tests at the National Bureau of Standards which were carried only to about this level in order to permit observations during the descent while the balloon radio signals were still of usable intensity. Curve (4) shows the comparison for the fifteen simultaneous radio soundings at the National Bureau of Standards and the Naval Air Station. Curve (5) shows the comparison for thirty practically simultaneous radio and airplane soundings at the Naval Air Station. The dotted curve shows the comparison data for 25 similar comparative soundings reported last year.[3]

The results shown by curves (2) and (3) are probably most representative of the accuracy of temperature observations obtained under field conditions, for the following reasons: (1) The comparative data obtained in the soundings at the National Bureau of Standards were considered to be somewhat favorable to the radio sonde because a calibration* of the pressure-measuring element was made within a few days of each sounding and because some of the comparisons were made between data furnished by the same instrument (ascending *vs.* descending values). (2) The comparative data between the National Bureau of Standards and the Naval Air Station soundings were considered to be somewhat unfavorable to the radio sonde because, even though the balloons were released from points only 10 miles apart, there was evidence in several of the tests of differences in the characteristics of the air masses sounded by the two balloons.

The comparative data between the radio and airplane soundings at the Naval Air Station were discounted somewhat because of evidence that the airplane data often exhibit materially different characteristics than the radio sonde observations. (Also because of the time differences in up to 25 percent of the soundings.) This phenomenon was reported in a previous paper.[3] Several tests in which simultaneous radio soundings were made at the National Bureau of Standards and the Naval Air Station at the same time as an airplane sounding was carried out showed that the two sets of radio data agreed better than either set agreed with the airplane data. A case where the airplane data were obviously at fault is shown in Fig. 3. In this

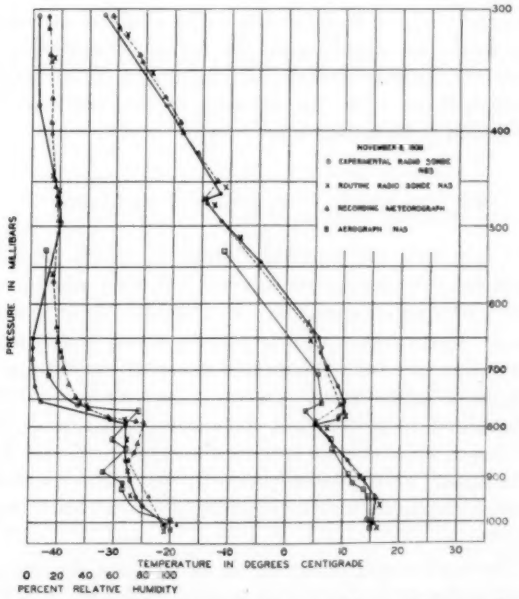

FIG. 3. Results of comparative soundings with two radio sondes, a recording meteorograph, and an aerograph. (The humidity data represented by the graph with solid-circle symbols were obtained with a new electrical hygrometer.[1])

illustration, the graphs with open-circle symbols refer to the radio sonde observations at the National Bureau of Standards, the graphs with cross symbols to the radio sonde observations at the Naval Air Station, the graphs with triangle symbols to a recording meteorograph carried by the N.B.S. balloon, and the graphs with square symbols to the airplane observations.

* In the method adopted for comparing the data, any error in the measurement of pressure results in an apparent error in the temperature measurements.

Note that the airplane sounding gave essentially different data.

Assigning equal errors to the radio sonde and the recording meteorograph readings, it will be seen from curves (2) and (3) that for temperatures above −50°C. some 95 percent of the radio sonde observations are accurate to within 1°C.; and some 80 percent of the observations are accurate to within 0.5°C.

The specifications for the flight performance of radio sondes furnished to the U.S. Weather Bureau this year call for agreement of 60 percent of the temperature observations with those of a check recording instrument (or a second radio sonde), carried on the same balloon, to within 2°C. It will be seen that any one of the comparison tests reported in Fig. 2 more than complied with the requirement. The specifications for laboratory performance call for an accuracy of the temperature observations within 1°C. between +30° and −50°C. and within 2°C. between −50° and −70°C.; an accuracy of the humidity observations within 5 percent relative humidity between 20 percent and 95 percent relative humidity (above 0°C.); and an accuracy of the pressure measurements within 5 millibars in the pressure range of from 1050 to 50 millibars. Five samples were subjected to flight similitude tests in the laboratory by the Weather Bureau in which an attempt was made to approximate the temperature-pressure conditions encountered during the ascent of the radio sonde balloon. The performance of the instruments was found to be satisfactory.

IV. Experience with Radio Soundings

In order for the Weather Bureau to obtain the full value from its aerological observations, they must provide a continuous sequence, *i.e.*, a regular, daily schedule of observations, which can be taken practically simultaneously with the ground observations throughout the Weather Bureau network, provide accurately determined meteorological data from the surface to heights of 20 kilometers or more above sea level, and the data must be available promptly at each Weather Bureau station for dispatching reports to other points.

The ideal arrangement would be to make the observations simultaneous at each level at 7:30 a.m., E.S.T., which is the time of the ground observations, from which the various morning charts are constructed. Practical considerations make it necessary to start the observations considerably earlier, namely 5:00 a.m., E.S.T., for upper-wind pilot-balloon observations and 4:00 a.m., E.S.T., for airplane and radio sonde observations. The observations must be worked up in time for forwarding by 7:11 a.m. It is hoped that in the near future this lapse of time can be greatly reduced; investigations now under way show promise of permitting a considerable later time of release of the radio-sonde balloon. The new codes inaugurated by the Weather Bureau on August 1, 1938, contribute to this aim by shortening the time required to prepare the observational data for transmission. Experiments are being carried out at the National Bureau of Standards to develop a rapidly responding humidity element to replace the hair hygrometer (the present limiting factor on the rate of balloon ascent). In addition, the Weather Bureau is conducting experiments to determine if the ascensional rate of the radio sonde balloon may be speeded up at levels above those at which the humidity observations are important.

If the transmission of the radio-sonde observations is delayed beyond the 7:11 a.m. schedule, it loses practically all its value for forecasting purposes, and the value of the other airplane and radio sonde observations is reduced.

The inauguration of radio sonde operation has resulted in great improvement in the regularity of the daily schedule of observations. This may be illustrated by a comparison of the observations for the first few months of operation at Sault Ste. Marie, Mich., with corresponding airplane observations made over the same period in the previous year. (See Fig. 4.) While Sault Ste. Marie was chosen because of its usual adverse weather conditions, nevertheless it represents a reasonable choice for the comparison because of the importance of the observations from this outpost station. Note that the improvement in regularity became more pronounced as the winter season was approached. For stations operating under favorable weather conditions (for example, Oakland, Cal.), the regularity of the daily scheduled observations obtained with the radio sonde is about equal to that of last year using airplane soundings, as may be illustrated by a comparison of the Oakland, Cal., airplane and radio sonde observations for corresponding months. (See Fig. 4.)

Radio sonde operation has also offered a marked improvement in the heights to which observations are obtained as is indicated by Fig. 4. The seven radio sonde observation stations have frequently all reached heights into the stratosphere several days in succession and from these data it has been possible to construct tropopause maps covering the country. From these maps it has been possible to verify the "multiple tropopause" observed in Europe by Bjerknes and Palmen.

The adoption of the radio sonde program has resulted in a loss of some data that was previously taken by airplane, that is, the heights of cloud bases and tops, haze layers, the turbulent conditions of the air, and levels where ice formation takes place. It is agreed, however, that the increase in the heights of the soundings by 3 or 4 times and the regularity of observations under adverse weather conditions outweigh the disadvantages of the observations which have to be sacrificed, particularly since the heights of the cloud bases and tops may be estimated from the trend of the humidity record.

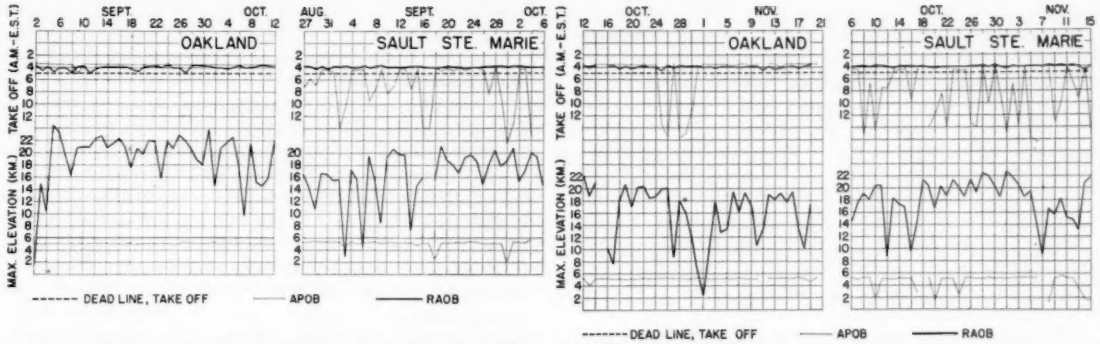

FIG. 4. Comparative data for corresponding months of 1937 and 1938 showing regularity and range of upper-air observations with airplane and radio soundings at Oakland, Cal., and Sault Ste. Marie, Mich. (While weather conditions at the Sault Ste. Marie station are unfavorable to airplane operation, the data are of particular importance for information on the development of cold waves.)

The data taken to establish the accuracy of the radio sonde observations under field conditions were discussed in the preceding section. With a network of observing stations, there are added means for detecting errors in the observations, as will appear from the following. After minor difficulties at the start of the program had been overcome, these independent means provided corroborative evidence that the accuracy of the observations were within the described limits, or at least within the limits of detection of the check methods evolved. These methods are based largely on comparative analysis of the soundings for a given area. From such analysis, any deviation in trend of the observations at any one of the stations is readily detected.

REFERENCES

[1] Diamond, H., Hinman, W. S., Jr., and Dunmore, F. W., *A Radio Meteorograph System with Special Aeronautical Applications*, Journal of the Aeronautical Sciences, Vol. 4, No. 6, pages 241–248, April, 1937. Diamond, H., Hinman, W. S., Jr., and Lapham, E. G., *Performance Tests of Navy Radio Meteorograph System*, Journal of the Aeronautical Sciences, Vol. 5, No. 12, pages 484–490, October, 1938.

[2] Lange, K., *The Application of the Harvard Radio Meteorograph to a Study of Icing Conditions*, Journal of the Aeronautical Sciences, Vol. 6, No. 2, pages 59–63, December, 1938. Samuels, L. T., *The Weather Bureau's Radio Meteorograph Program*, Monthly Weather Review, Vol. 66, pages 93–95, April 1938. Harmantas, C., and Keily, D. P., *Series of Radio Meteorograph Soundings during February-April, 1937*, Monthly Weather Review, Vol. 65, pages 219–229, June, 1937.

[3] Diamond, H., Hinman, W. S., Jr., and Lapham, E. G., *Comparisons of Soundings with Radio Meteorographs, Aerographs, and Meteorographs*, Bulletin of the American Meteorological Society, Vol. 19, pages 129–141, April, 1938.

Book Review

The Book of the Sextant, by A. J. HUGHES; Brown, Son & Ferguson, Ltd., Glasgow, 1938; 90 pages, 5s.

It seems very fitting that this book should be written by Mr. A. J. Hughes, an international authority on the subject. Messrs. Henry Hughes & Son, Ltd., advertise the fact that they have been in Fenchurch Street for more than one hundred years, manufacturing precision navigational instruments. Captain Bligh of "Mutiny on the Bounty" fame was a user of Husun equipment, and now, in 1939, the Royal Air Force, as well as marine navigators and private airmen, are finding their way by means of Husun instruments.

Henry Hughes & Son was the first company to place the averaging sextant, an instrument described at length in "The Book of the Sextant," on the market, thereby filling a long-felt need. It had become obvious that to obtain reasonable accuracy with a sextant in the air, an average of the sights taken would have to be made. The tedious operation of taking a mean of ten observations and reducing them to a position was a serious matter. In addition, the high speeds of modern aircraft made the delay in reducing observations to positions a costly one. It therefore became a clear case of necessity mothering the invention.

In 1936 the urgent need of an averaging sextant was brought to the attention of the Messrs. Hughes, who within the space of three months designed, built, and tested such an instrument. As far as is known, this averaging sextant is the only one available at this time, although others are in development.

Another of Mr. Hughes' original designs is the Gothic sextant for marine use. This is also fully described in the book.

Included in the book is a history of the sextant, with notes on such instruments as the astrolabe and the quadrant, which is brought up to the latest developments for both marine and air use. Finally, there is a chapter on equipment such as the three-arm protractor, the artificial horizon, the star globe, and position finders, with a discussion of their use, all of these being instruments used in connection with the sextant. Of particular interest is the section devoted to the sextant telescope, giving details of its principles and construction.

Altogether, this small book of only ninety pages is an excellent guide for those interested in navigation instruments. It is freely illustrated with both drawings and photographs, and its text contains the last word on sextants, their construction, use, and adjustment.

P. V. H. WEEMS
Weems School of Navigation

Institute Notes

International Congress of the Aeronautical Sciences

Plans for the International Congress of the Aeronautical Sciences, to be held from September 11 through September 17, 1939, are rapidly nearing completion.

As the Journal goes to press 32 papers by foreign authors have been scheduled for the technical sessions. These cover all branches of the aeronautical sciences and promise to give a comprehensive picture of aeronautical research in many foreign countries.

Preliminary programs of the meeting will be sent to members as soon as is practicable.

Honors

Glenn L. Martin, an Honorary Fellow and Benefactor Member of the Institute and President of the Glenn L. Martin Company, received an honorary Doctor of Engineering degree from the University of Maryland at the June commencement.

J. H. Kindelberger, a Fellow of the Institute and President and General Manager of North American Aviation, received an honorary Doctor of Engineering degree from the Polytechnic Institute of Brooklyn at its June commencement.

Harold E. Gray, a Pilot Member of the Institute, and Captain, Atlantic Division, Pan American Airways, received an honorary Master of Engineering degree from the University of Detroit at its June commencement.

Proceedings of the Rotating Wing Aircraft Meeting

The proceedings of the Rotating Wing Aircraft Meeting in Philadelphia on October 28 and 29, 1938, have been mimeographed and are available at $2.00 each from Ralph H. McClarren, Secretary, The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia, Pennsylvania. The meeting was sponsored by the Philadelphia Branch of the Institute and the publication of the proceedings was also a project of that branch.

This 155-page report includes the complete text of every paper presented at the meeting as well as of the discussions following. It is recommended to all those interested in rotating-wing aircraft. The papers included are listed in the November and December, 1938, issues of this Journal.

Reprints of Dr. Alexander Klemin's paper on "Principles of Rotary Aircraft," comprising 70 pages and 32 illustrations are also available at the above address at $1.00 each. This paper was presented at a joint meeting of The Franklin Institute and the Philadelphia Branch of the Institute on October 27, 1938.

Pacific Coast Annual Meeting

The first Pacific Coast Annual Meeting of the Institute was held at the California Institute of Technology in Pasadena on June 15, 16, and 17, 1939. About two hundred people registered for the technical sessions.

From the standpoint of the excellence of the papers presented and of the discussions following their presentation, the meeting was one of the most successful the Institute has held. Only two or three papers were scheduled per session, thus allowing sufficient time for discussion.

Brief digests of the papers follow:

Meteorology

The meeting opened on Thursday afternoon June 15th with a session on Meteorology, of which Dr. Irving P. Krick of the California Institute of Technology was chairman.

The first paper, by Dr. George Taylor of Western Air Express, was entitled "Influence of Topography on Weather Forecasting at Salt Lake City, Utah." He described in general the effects of configuration and orientation of cold fronts on the weather in the vicinity of Salt Lake City. The most important topographical influence in the immediate vicinity is a range of mountains running in an east-west direction. As a result there is a comparatively large difference in rainfall between the north and south slopes.

The next paper, by B. C. Haynes of the Boeing School of Aeronautics, on "Laboratory Experiments in Meteorology" described a number of interesting illustrative demonstrations especially adapted for classroom use. A small water tank with glass walls capable of being divided into two or more compartments is used. By the addition of salt and coloring fluid, density differentials are established. Lifting the barriers separating the compartments effectively demonstrates phenomena connected with the passage of fronts and the development of occlusions. The paper closed with motion pictures showing the development and dissipation of clouds under various conditions.

The last paper of the Meteorology session, by F. K. Kirsten and F. C. Rosacker of the University of Washington gave a short description of a new type of neon illumination suggested for use in landings in foggy weather. The illumination source is a special type of neon unit operating at a much higher current load than that used for the normal advertising neon signs. In addition to lighting the runways the lights also project a beam into the fog which is visible on top of the fog layer, thus guiding the pilot into the field by means of a beam which can be seen through the fog or haze.

Structures

F. W. Herman of the Douglas Aircraft Company was chairman of the Thursday evening session on structures.

The first paper, by Dr. E. E. Sechler of the California Institute of Technology, consisted of a summary of the work done in the structural laboratory at that Institute during the past year. There were five research projects reported on, and a brief discussion of the problem, method of attack, and the results was given. The problems discussed were: (1) General stability of stiffened metal cylinders. (2) The failing strength of elliptical cylinders representing wing nose sections. (3) Problems relating to the failure of stiffened flat panels under compression. (4) The failure of unstiffened cylinders under compression loads. (5) Repeated tension impact of aircraft materials.

Following this, a paper on "Corrugations Under Combined Compression and Shear Load" by Paul A. Sanderson and J. Robert Fischel of the Lockheed Aircraft Corporation, was presented. The paper opened with a description of a test on a box-wing section which was conducted at the Lockheed Aircraft Company. This section was loaded with a combination of bending and direct shear loads, and a curve was given showing the failing bending strength of such a structure for any combination of the two loading conditions. The paper indicated a new field of research because of the fact that the specimen was constructed of a combination of elements including corrugated compression skin, Wagner Shear Webs, stiffened flat sheet on the tension surface.

Aerodynamics

Dr. Th. von Kármán of the California Institute of Technology was chairman of the Friday morning session on Aerodynamics.

F. K. Kirsten and F. S. Eastman of the University of Washington presented a paper on "The University of Washington's New

250 m.p.h. 8 × 12 Foot Wind Tunnel." The tunnel is of the double return type and utilizes several novel features. A tripod model mounting was chosen to minimize interference and tare drag. The balance system is of the electromagnetic type and measures the six components simultaneously. All components are registered on meters, and a photograph of the instrument panel gives all of the necessary information on routine tests.

Dr. H. Reissner of the Armour Institute of Technology presented the next paper, on "The Airfoil of Minimum Total Resistance." The analysis was similar to Munk's method for obtaining the planform of minimum induced drag. The results are in such form as to define an angle analagous to the induced angle of attack by means of which any planform can be corrected to give minimum total drag.

C. L. Johnson of the Lockheed Aircraft Corporation was chairman of the Friday afternoon session on Aerodynamics.

Paul E. Hovgard of the Curtiss Aeroplane Division, Curtiss-Wright Corporation, gave a paper on "Means for Suppression of Interference Burble." It was found that the interference burble could be retarded by changing the wing section and moving it forward. This leads to the use of "blisters" on the leading edge between the fuselage and the engine nacelle. One of the most important factors seems to be the amount of fuselage ahead of the wing leading edge, in terms of the airfoil chord. The use of blisters is a means of decreasing this length.

Albert Gail of United Air Lines Transport Corporation presented a paper on "Analysis of Best Rate of Climb and Ceiling as Affected by Ice Accretions." The conditions for maximum rate of climb were determined on the basis of Oswald's algebraic representation of the polar as a function of the variation of the thrust horsepower with speed. It was shown that ice and other factors affecting the horsepower required have negligible influence on the slope of maximum rate of climb *versus* altitude. Oswald's airplane efficiency factor was interpreted in terms of a "Pseudo Aspect Ratio." The full scale tests analyzed showed that the effects of increased surface irregularities upon maximum rate of climb are equivalent to increments of induced drag; the parasite drag may be considered as approximately invariable.

Richard W. Palmer of the Vultee Aircraft Company was chairman of the Saturday morning session on Aerodynamics.

L. B. Rumpf, Jr., and R. S. Schairer of the California Institute of Technology presented a paper on "Wake and Boundary Layer Surveys in the Wind Tunnel and in Flight." The paper described the development of apparatus for determining the transition point on airfoils in the wind tunnel and in flight and gave results of these measurements along with total head wake surveys. A small car moving along a track bolted to the upper surface of the wing carried a small total head tube for locating the transition from laminar to turbulent flow in the boundary layer. The measurements showed among other things the pronounced effect of exposed rivet heads on the transition point and drag of modern high speed wings.

Airplane Design

Hon. E. P. Warner of the Civil Aeronautics Authority was chairman of the Friday evening session on Airplane Design.

Jean Wylie of the Douglas Aircraft Company presented a paper on "Dynamical Problems of Tricycle Alighting Gear." He gave a brief account of the theoretical aspects of the tricycle alighting gear problem, indicating that at least a first approximation to the solution can be obtained by theoretical methods. Probably the most uncertain factor is the magnitude of the tire friction. The problem of the nose wheel resolved itself into two forms of instability one which Mr. Wylie called the kinematical stability, and the second the dynamic instability of the wheel. The various parameters entering the problem were discussed, and the dangerous design regimes were pointed out. Motion pictures of the nose wheel on a modified Douglas Amphibian under various types of landing conditions were shown.

C. L. Johnson and R. L. Thoren of Lockheed Aircraft Corporation gave the next paper, on "Wing Stalling Tests on a Modern Transport Airplane." The paper discussed the stalling characteristics of the Lockheed 14 before and after its modification by the use of tip slots. One wing of the airplane was covered with tufts, and motion pictures were taken during flight as the airplane was flown through the stall regime. The effect of flaps and power were shown and the final series of pictures indicated the improvement due to the installation of a series of fixed slots near the tip of the wing.

T. P. Wright of the Curtiss-Wright Corporation was chairman of the Saturday afternoon session on Airplane Design.

Dr. J. E. Lipp of the Douglas Aircraft Corporation presented a paper on "Shear Field Aircraft Spars." The paper discussed the design of aircraft wing spars with particular emphasis being placed on spars having webs in the incomplete tension field state. Most of the information which he presented was taken from tests carried out at the Douglas Company on spar designs for the DC-4. The effect of various sheet thicknesses on the design was discussed and the method of choosing the vertical stiffener area was indicated.

Dr. A. E. Lombard of the California Institute of Technology gave the next paper, on "Flutter Can Be Avoided." The paper included a compilation of all existing data on flutter, drawing extensively from the theories of Kassner, Küssner, Pugsley, Theodorsen, and von Kármán and Sears. The author recommended complete static and dynamic balancing of control surfaces to eliminate flutter. He finds that the most important parameters affecting flexural-torsional wing flutter are (1) the position of the inertia axis, (2) the torsional frequency, and (3) the radius of gyration of the wing mass about the inertia axis. He concludes that the speed of airplanes should be restricted to two thirds of the critical speed for any mode of flutter, divergence, or aileron reversal.

Power Plants

W. P. Gwinn of Pratt and Whitney Aircraft was chairman of the Saturday evening session on Power Plants.

R. F. Gagg of the Wright Aeronautical Corporation, Curtiss-Wright Corporation, gave the first paper, on "Selection of Aircraft Engines for Specific Services." The method suggested was essentially one of applying a rating scale to items which affected the performance, safety, economics, and maintenance of an aircraft engine, and then setting up a scoring chart for the various engines under consideration. It was pointed out that the rating scale presented was completely tentative in nature, and that it would be advisable for each manufacturer to rate the items involved to suit the design at hand.

Carlton Kemper of the National Advisory Committee for Aeronautics presented the concluding paper, on "Aircraft Engine Research of the National Advisory Committee for Aeronautics." The development of the N.A.C.A. cylinder with greater fin area, resulting in lower working temperatures and greater efficiency, was described. Work on fuel injection engines for use with safety fuels, detonation studies, problems connected with Diesel engines, etc., were discussed. Very high speed motion pictures showing the details of detonation were shown.

An interesting program of luncheon and dinner talks on various scientific subjects was carried out. On Thursday evening Dr. J. A. Anderson of the California Institute of Technology, spoke on "The 200 Inch Telescope" giving some of the engineering problems encountered and their solutions. Dr. H. F. Bell of the Soil Conservation Service spoke at the Friday luncheon on "Mud Clouds in Water," showing the processes of filling and mixing which take place when streams merge or flow into reservoirs. On Friday evening Brian Sparks of Pan American Airways showed motion pictures taken while "Flying the Pacific," showing particularly the conditions and native life on the stops en route to the Orient. Dr. Chester Stock of the California In-

stitute of Technology, spoke at the Saturday luncheon on "Early Californians." He described fossil remains of early life in California and their significance from a geological standpoint. On Saturday evening there was a demonstration of high voltage phenomena at the High Voltage Laboratory. These talks and demonstrations, all accompanied by slides or motion pictures, were particularly well received. The Institute is indebted to the lecturers for their cooperation.

The California Institute of Technology kindly placed its lecture room facilities and the Athenaeum at the disposal of the Institute. The success of the meeting is due in a large measure to the efforts of Dr. A. L. Klein, chairman of the Program Committee, who was in charge of the arrangements, and to the members of the Program Committee, J. L. Atwood, Hall L. Hibbard, Clark B. Millikan, Richard M. Mock, Richard W. Palmer, Arthur E. Raymond, and F. R. Shanley.

Joint Meeting of the Institute and the Soaring Society of America

A joint meeting of the Institute and the Soaring Society of America was held in Elmira, New York, on June 30 and July 1, 1939, in connection with the Tenth Annual Soaring Contest. Presentations of prepared technical papers were followed by interesting discussions of soaring problems.

On Friday evening, June 30th, the joint meeting opened with an address of welcome by R. E. Franklin, Chairman of the S.S.A. Meeting Committee, who also acted as chairman of the session. Arthur L. Lawrence, Chairman of the S.S.A. Contest Board, reviewed the achievements in gliding in this country and predicted great progress and popularization in the next decade.

The next paper on the program, by Commander Ralph S. Barnaby, was entitled "Gliding and the Aircraft Industry." He solicited the interest and help of the aircraft industry to further the development of gliding and soaring in this country. He pointed out that experience in gliding and soaring should be useful to the airplane pilot in the same way as free ballooning is useful to the airship pilot. He recounted the outstanding problems confronting the designers of sailplanes and their analogy with those of the airplane designer.

Eastman N. Jacobs of the National Advisory Committee for Aeronautics was chairman of the Saturday afternoon session on "Design and Operation."

R. C. Platt of the National Advisory Committee for Aeronautics gave the first paper, on "N.A.C.A. Research and Design Methods Relating to Stability and Control." Recommendations covering all phases of the aerodynamic design of sailplanes based largely on N.A.C.A. data were given. Some fifty references to the literature made the paper quite complete.

Dr. Wolfgang Klemperer of the Douglas Aircraft Company presented a paper on "Research Problems in Towed Flight." He recommended experiments with towed gliders to (1) find and ascertain dangerous conditions, (2) find under what conditions loss of control occurs, and (3) study problems connected with inadvertent loss of towing force. It would also be advisable to measure the forces transmitted by the tow line under all conditions.

Arthur B. Schultz of the Kermath Manufacturing Company, Detroit, gave the next paper, on "The Use of Ballast." He pointed out that for cross-country gliding it is in many cases advisable to ballast the sailplane. This enables a higher gliding speed with little sacrifice in sinking speed, and flight through down-currents can be made more rapidly than without ballast.

Dr. H. R. Byers of the U.S. Weather Bureau was chairman of the Saturday evening session on Meteorology.

The first paper, by R. C. du Pont, President of the S.S.A., was entitled "On American Soaring Technique." He pointed out that the records established recently have resulted from improvement of the mechanical technique as well as from increased knowledge of soaring meteorology. The use of "cloud streets" is of great assistance for cross-country gliding. It was predicted that great advances in gliding and soaring will follow the development of blind flying equipment adapted to sailplanes.

Dr. H. R. Byers gave the next paper, on "Meteorological Aspects of Thunderstorm Activity." The paper traced the theories of thunderstorm formation, potential gradients, and the generation of the potentials resulting in lightning. The author recommended observations and records of temperature, potential gradients, etc., by soaring pilots.

E. F. Minser of Transcontinental and Western Air, presented the concluding paper, on "Meteorological Conditions Associated with Aircraft Lightning Discharge and Atmospherics." The paper described investigations of the damage to airplanes due to lightning strikes and the conditions under which strikes occur. The damage to the structure of the plane and equipment was, in all cases, of minor nature. The rules for pilots, formulated as a result of these investigations, were quite effective in that those regions of the clouds where strikes were most likely to occur could, in most cases, be readily avoided.

Those who attended the meeting were privileged to witness gliding and soaring under practically ideal conditions. The facilities and physical equipment at Harris Hill, developed largely by the W.P.A., are of the best.

One hundred or more attended each of the technical sessions. The informal discussions of the various phases of sailplane design and operation, which followed the presentation of the papers, were especially informative and to the point.

The program committee for the joint meeting, comprising R. E. Franklin and Dr. K. O. Lange, chairmen, A. L. Lawrence, E. R. Southee, C. H. Gale, M. F. Stoughton, Commander R. S. Barnaby, W. R. Enyart, Dr. W. B. Klemperer, Prof. E. A. Stalker, and T. P. Wright, deserves great credit for arranging the interesting program.

Branches

Georgia School of Technology. At a meeting on May 16th, E. W. Fuller of American Airlines presented a paper on "Feathering Propellers in Airline Operation," to the members of the Student Branch. The paper was prepared jointly with M. G. Beard and was presented previously at the Aeronautics Meeting of the Society of Automotive Engineers.

University of Michigan. A meeting of the Student Branch was held on June 1, at which Prof. E. A. Stalker spoke on the research facilities at Langley Field. His talk was based on the recent inspection tour of the laboratories.

Rensselaer Polytechnic Institute. At a meeting of the Student Branch on May 10th the following officers were elected for the coming school year: R. A. Wells, Chairman; S. Fuller, Treasurer; A. P. Paine, Secretary; Prof. A. J. Fairbanks, Honorary Chairman.

University of Washington. A meeting of the Student Branch was held on May 17th at which officers for the coming school year were nominated. Following this, several of the papers given at the Annual Meeting of the Institute were discussed. At a meeting on May 22nd the following officers were elected: John R. Howard, Chairman; Myles D. Erickson, Vice Chairman; and Earl R. Barber, Secretary-Treasurer.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

A Catapult Has Been Built at The Institute de Lille. By means of airplane models realizing geometric and dynamic similitude, a study of the influence of horizontal and vertical gusts has been started at the Institute of Fluid Mechanics at Lille. In order to obtain dynamic similitude it is necessary to measure the moments of inertia of the model and also to calculate the additional masses which it is found advisable to place at different points on the wings and fuselage. The catapult will assist in the general methods of research on the free model at the Institute, where the influence of the gusts on the flight of airplanes is being studied by means of models launched by a catapult operating under compressed air across the experimental jet of a vertical or horizontal wind tunnel. Catapult is described and illustrated. *Les Ailes*, March 30, 1939, page 8, 2 illus.

Comparison of the Principles of Propulsion of Cetaceous Animals and Fish with Those of Birds. M. Tricot. Following numerous observations on birds, the author has undertaken to analyze certain equivalences of propulsion between the displacements in aerial and aquatic fluids. The principles of propulsion of cetaceous animals and fish are compared with those of birds. *L'Aérophile*, March, 1939, pages 63–65, 7 illus.

Aircraft Design

Behavior of an Airplane Furnished at the Same Time with Lower Flaps and Wind Vanes. L. Constantin. Use of flaps on the lower surface of the wing on modern equipment which should be braked in flight so that the gliding speed can be increased and the landing speed decreased. Qualitative and quantitative analyses of the operation behavior of the aircraft with flaps and wind vanes are given. There is shown a novel example of the unequaled efficiency of the wind vane in the difficult cases of piloting. *L'Aéronautique*, March, 1939, pages 118–120.

Anticipations of 700 Kilometers per hour. Speeds of 500 km./hr. during the next year, and 600 km./hr. in two or three years in current service are predicted. Consequences of these speeds are forseen in regard to navigation, bombardment, pursuit, and reconnaissance. Fuselage will have an atmosphere conditioned in temperature, pressure, and humidity, not for stratospheric flights but to permit the airplane to climb to 5000 or 6000 meters five or six times in an hour and twenty times per day. *Rev. de l'Armée de l'Air*, March–April, 1939, pages 128–130.

"Perfect Wing" for Aircraft. New type of wing worked out by D. R. Davis is said to have solved the problem of giving an airplane maximum possible lift with minimum possible drag and to increase the speed of airplanes at least 20 percent. Sample wing has been constructed at the California Institute of Technology. Brief reference. *Automotive Industries*, May 15, 1939, page 632.

Scientific Predictions of the Maximum Speed of Aircraft. J. Angeli. Limit will be 1000 km./hr. for racing airplanes and pursuits, 945 km./hr. for the transport aircraft and bombers, and 880 km./hr. for aircraft of 100 tons. From the performances already attained and from a knowledge of the barriers which the speed of sound imposes on conventional airplanes, it is possible to trace the curve of the evolution of speed limits. This is a parabola analogous to that of growth of the living beings, and of development of human industries. Method for calculating the limits and influence of number of engines and propellers on the airplane are considered. Table shows characteristics and performance of the 100,000-kg. long-range, the 20,000-kg. transport or bomber, and the 3000-kg. racer-pursuit, attaining, respectively, 880, 945, and 1000 km./hr. *Les Ailes*, April 20, 1939, page 7, 1 illus., 2 tables.

Pursuit Airplanes Will Make 830 Kilometers per Hour in 1945. J. Angeli. Limit of 1000 km./hr. will be attained only in 1955. Afterward it will be necessary to pass on to unusual arrangements of motors which will not be influenced by the speed of sound. Probable evolution of aircraft design is examined and it is said that, contrary to current opinion, it is at ground level that the speed limit will be reached. Furthermore, propellers should be of very large diameter turning very slowly and should have a much larger number of blades than at present.

The high-speed airplane will have to fly much nearer the ground as its speed is raised. Propeller r.p.m. will have to be lower as the maximum speed is higher, and as the tonnage of the airplane is more considerable. Number of propeller blades should increase with the speed of the airplane. Since increase in number of blades renders operation of the mechanism for varying pitch in flight very sensitive, it is probable that variable-pitch propellers will be progressively abandoned, at least for aircraft of small tonnage, the low load per horsepower of which will partially compensate for the inconvenience of the fixed pitch at take-off. For ultra-high-speed airplanes of the future two coaxial inverted propellers will be obligatory. Because of the considerable diameter of the optimum propeller, it does not seem that high-speed airplanes will carry a large number of engine-propeller groups but will be bimotors with four coaxial propellers, arranged two by two. Airplanes of very great tonnage will have an extremely low aspect ratio. Limits of utilization of the airplanes foreseen are discussed. *Les Ailes*, April 27, 1939, page 7, 2 illus.

A Composite Design for a High-speed Mail-Carrier. Suggested design for the upper component of the Mayo Composite Aircraft which would be used to carry mails between London and New York, cruising at 250 m.p.h. and covering the distance of 3750 miles plus 300 miles for emergencies. First step is to take the floats off the Mercury and replace them with a retractable undercarriage, and second is to increase the wing loading. A bigger crew and plenty of room in the fuselage both for them and the freight and mail are needed so that power should be raised to retain the wing in its entirety both as regards its span and area. All-up weight is 35,000 lb. This proposed design is discussed in detail and specifications are given. Refueling in flight for the upper component to whatever loaded weight it can be launched by the Mayo composite aircraft is also suggested. Curves showing rate of climb and ceiling given on another page. *Aeroplane*, May 10, 1939, pages 597–599, 608, 5 illus.

An Elementary Study of the Spin. J. H. Crowe. Several methods available for preventing autorotation or reducing autorotation speeds; effects of tip slots; method of stabilizing a wing and reducing autorotative tendencies proposed by Schrenk (two slits), and the "Diruttore" gear originated by Mattioli; a sharp nosed airfoil as another method of avoiding unstable moments; trim of airplanes at higher angles of incidence; general relationship existing between incidence in a spin and speed of rotation; increase in speed of spin which follows an applying a diving moment, and criterion for stability of the spin; equation for aerodynamic pitching moment in a spin; center of gravity position; stagger of a biplane in relation to spinning; difference between monoplane and highly-staggered biplane; destabilizing influence of seaplane floats on pitching moment; enormous importance of the yawing moment; rolling and yawing moments and rudder control; stability of yawing moment; equation for aerodynamic yawing moment; and importance of yawing moment due to the body in the design of an airplane which shall be free from flat spinning tendencies. Continued. *Aircraft Engineering*, May, 1939, pages 203–208, 9 illus., 8 equations.

Hypothetical Modernity. Cutaway drawing shows a hypothetical military airplane which represents no particular class but can carry the equipment necessary for bombing, fighting, ground attack, and reconnaissance. Hypothesis corresponds with certain Frencht win-engined general-purpose types now going into service and with the Bristol Blenheim which can also be used for a variety of duties, including fighting. Hypothetical machine is arger than the Blenheim and might carry a torpedo although shell-firing guns in bottom of fuselage would have to be replaced by machine guns. Airplane is designed with tricycle undercarriage, and vee twelves of the Rolls-Royce Merlin type with radiators arranged on the aerodynamic principle and placed in ducts in the wing, cooling air being ejected through slots in the fuselage after a scheme which is the subject of a French patent. Exhaust pipes are led to tail ends of nacelles where they eject through slots. Exhaust-driven superchargers are not fitted. Two shell guns fire out under the nose, and a third is in a power-driven turret with retractable fairing and there is a fourth optional weapon for firing out through the floor under the fuselage. *Flight*, May 18, 1939, pages 512–513, 1 illus.

The Latest from the N.A.C.A. Editorial comment on the new N.A.C.A. wing section, which is claimed to give laminar flow over practically the whole surface and a reduction of drag of about 67 percent. It is thought that the announcement may be connected with the release of information about the new two-engined Consolidated Model 31 flying boat, which has an extremely thin wing for which extraordinary qualities are claimed, including an increase in maximum speed of about 20 per cent over airplanes of the same size with conventional wing sections.

"Although the rumors are probably, as always, exaggerated there is undoubtedly some real point in Dr. Lewis' remarks. Whether the N.A.C.A. is dabbling with some method of boundary layer suction or whether it has made some fundamental discovery to reduce drag is still unknown." Brief editorial and illustration of the Consolidated flying boat. *Aeroplane*, May 24, 1939, page 644.

Simultaneous Equations. J. Morris. Approximate and successive approximation method based on iteration. Description of iteration method by example and theory; conditions for convergency of the process; convergency of equations of the "normal" type; transformation of any set of simultaneous linear equations to a normal system; and convergency of iteration process for a normal group of simultaneous equations. *Aircraft Engineering*, May, 1939, pages 199–200, 4 tables, many equations.

The Test Pilot Looks at Aircraft Safety. M. N. Gough. Comments on controllability and maneuverability from the point of view of an N.A.C.A. senior test pilot. Tests made to date on existing airplanes indicate that many reasonably desirable characteristics are not unattainable. Their present absence is due for the most part to performance compromises. Safety in flight can be greatly improved. Lateral and longitudinal control and stability, elimination of rolling instability as the basic solution of the stalling problem, and take-off and landing control are considered. *Aviation*, May, 1939, pages 20–21, 80, 82, 84, 1 illus.

Summary of N.A.C.A. Investigations of High-Lift Devices. C. J. Wenzinger. Slotted types of flap appear to be the most promising on the basis of the aerodynamic characteristics listed, in particular the N.A.C.A. arrangement of the double-slotted flap. Results of intensive investigations of lift-increasing devices during the past ten years are summarized, covering: high-lift devices located at the leading edge of the wing, including the fixed auxiliary airfoil, and fixed and movable slots; trailing-edge devices including non-slotted and slotted flaps; and miscellaneous devices including low-aspect-ratio wings, boundary-layer control, and rotating cylinders. Various basic arrangements compared are of the infinite-aspect-ratio characteristics, corresponding to an effective Reynolds Number of 3,500,000 and including maximum lift coefficient, increment of maximum lift coefficient due to the lift-increasing device, and ratio of maximum lift to minimum drag which is an indication of speed range obtainable with a given combination. *S.A.E. Jour. (Trans.)*, April, 1939, pages 161–172, 31 illus.

Technical Notes. An ingenious system of control of under-surface flaps producing an effect of slots at all incidences of deflection, has been patented by a young sergeant-pilot of the school at Istres. Placement of the lower flaps in the wing is designed in such a fashion that it brings about a section of the correct flow between the under part of the wing and nose of the flap. Flap is designed as a small wing and is held by a rod above and by a lever below. *Les Ailes*, March 30, 1939.

Stress Analysis and Structures

A Low-Density Material for Aircraft Structures. V. E. Clark, Clark Aircraft Corp. Duramold, a material developed for aircraft structures, has a specific gravity which may be accurately controlled within ±3 percent, within a range from 0.5 to 0.9. Within this range, the strength and elastic modulus vary, roughly, as the density. In its final form this material is sufficiently non-hygroscopic and free from attack by fungi or molds and other kinds of deterioration to answer all practical requirements of airplane service operation. Specimens having a ratio of edge area to total area thousands of times as great as that existing in airplane shells, show an increase in weight of less than one percent after seven weeks of complete immersion, with negligible change in dimension, no deformation, and no change in physical characteris-

tics. Important physical characteristics of Duramold in four of its many forms are shown. In resistance to fatigue, based on allowable stress, for equal weight per unit area, Duramold is about 50 percent better than 17ST duralumin. There is no creep. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 6 pages, 1 table.

A New Method of Measuring Strain Distribution—Brittle Coatings. A. V. de Forest. Surface of the actual part whose design is being analyzed is coated with a coating of uniform brittleness and part is loaded in a manner simulating use, so that the coating is caused to rupture first at points of high strain concentration and later with higher loads in areas of more general strain distribution. By measurement of loads at which these rupture patterns form, strain concentration ratios can be computed as the inverse ratio of the loads required to form patterns on the respective areas. Actual strain values can be computed by calibration of the brittleness of the coating. Details of method developed at M. I. T. *Instruments*, April, 1939, page 113, 3 illus.

Advantages of Geodetic Design. C. L. Bates. Possibilities in airplane design offered by the geodetic principle of running load-carrying members as close to the contour as possible and spirally around the surface, and problems of construction, not the least of which is forming and joining a multitude of small curved parts. Construction offers high degree of torsional rigidity in fabric-covered structure. Vickers-Wellesley wing and fuselage structures are described. Geodetic designs in wood construction attempted in this country are considered in regard to weight and cost. Combination geodetic and monospar structure of an experimental wing under construction by the author at the Aero Industries Technical Institute is illustrated and discussed.

Short note on another page gives a few details of the Bicraft, a bimotored airplane of geodetic construction (two 50-hp. Menasco engines) which is being produced by North Pacific Aircraft Corporation, formed by G. Yates and A. D. Greenwood. *Western Flying*, May, 1939, pages 21–22, 32, 5 illus.

A Review of the Photoelastic Method of Stress Analysis. R. D. Mindlin. Methods for measuring principal stresses are described, covering Filon's, Neuber's graphical, lateral extensometer, air-film interference, stress-concentration, Favre's and Fabry's interferometer, Hiltscher's converging-light, and membrane methods, as well as electrical and numerical methods.

Special developments and applications taken up include: Goodier's hydrodynamic analogy; Biot's gravitational and thermal analogies; three-dimensional photoelasticity; special cases of three-dimensional systems; determination of σ_3, σ_2 and σ_1, in three-dimensional systems; dynamic problems; and some miscellaneous applications. Concluded. *Jour. Applied Physics*, May, 1939, pages 273–294, 29 illus., 25 equations.

The Practical Application of Explosive Rivets. O. Butter. Further notes from the Ernst Heinkel Flugzeugwerke in regard to the explosive rivet, closing head of which is formed by means of an explosive charge. Action of the rivet, comparison with hollow rivets, materials available for explosive riveting, advantages claimed, typical examples of parts in production of which explosive rivets were exclusively used, and freedom from hammer marking are discussed and illustrated. Diagrammatic sketch illustrates the forces acting on the Heinkel rivet. *Aircraft Engineering*, May, 1939, pages 215–216, 11 illus.

Aircraft

Those Built-In Slots. "Slots have made a most important difference to the handling characteristics of the Lockheed 14, according to reports by British Airways, Ltd." North American trainers and Lockheeds for the R.A.F. have also been fitted with slots. Drawings and templates were prepared from the first R.A.F. Lockheed so fitted to arrive in England, and from them slots were made for the Lockheed 14s.

Flight test report says that the slots have changed the stall characteristics entirely. Much confidence is gained by positive feel of the aileron controls at low speeds, such control now existing up to stalling point in the three-point landing position. No decrease in high speed, cruising speed or climb could be detected. Extreme wing tip is being made part of the stressed structure and a slot is to be made in it also. Photographs show how the slots have been made in the wings of the Lockheed 14. Short discussion of flight test results. *Aeroplane*, April 26, 1939, page 508, 4 illus.

BELGIUM

Another Tipsy Trainer. Fairey "M" trainer built to meet requirements of the Belgium Air Force and specially designed as a school machine, particularly an aerobatic trainer. Main structure of both fuselage and wings is tubular, all joints being bronze welded, a process which has been used successfully for some time in the Tipsy workshops in Brussels. Maximum speed 150 m.p.h. Cruising 125 m.p.h. Landing speed with flaps 44 m.p.h. Range 470 miles. All-up weight 1870 lb. Gipsy Major I engine. *Flight*, May 11, 1939, page 476b, 1 illus.

CZECHOSLOVAKIA

Benés-Mráz "Super-Bibi" Airplane. A. Frachet. Two-seater side-by-side monoplane designed for touring and training. Walter Minor-IV 85-hp. engine. Maximum speed 225 km./hr. Ceiling 5000 meters. Range 1100 km. at 200 km./hr. Long description of construction, characteristics and performances. *Les Ailes*, March 30, 1939, page 9, 3 illus., 1 table.

FRANCE

Caudron-Renault "Cyclone" Pursuit Airplane. Caudron-Renault Cyclone single-seater day-and-night pursuit and training airplane has a speed of nearly 500 km./hr., and a small angle of drive which permits it to attain with a great acceleration speeds exceeding 700 km./hr. Renault 12 R.01 No. 468 12-cylinder inverted-vee aircooled supercharged engine gives 450 hp. at 3600 meters and 500 hp. for take-off. Requirements of the modern pursuit are discussed and the Cyclone is described in regard to its construction, engine, radio equipment, characteristics, fuel and oil consumption, weights, speeds at various altitudes, and rates of climb to these altitudes. *L'Aérophile*, March, 1939, page 56, 1 illus., tables.

The Stability of the Autogiro in Flight and in Landing. Lt. Col. A. Verdurand. Author changes his opinion of the autogiro from the civil and military point of view, and points out the progress attained in the present autogiro of the S.N.C.A. du Sud-Est, in regard to: inherent stability; elimination of the risk of inverted flight during a dive; landing vertically; maneuverability; danger of nosing over after landing and a rotor hub developed by the S.N.C.A. which eliminates this risk; and vertical take-off. Means for assuring longitudinal and lateral stability of the autogiro in flight are briefly reviewed. *Rev. de l'Armée de l'Air*, March–April, 1939, pages 187–191, 1 illus.

GERMANY

Blohm and Voss Ha 138. Long-distance reconnaissance trimotored flying boat (three Junkers Jumo 205c 600-hp. heavy-oil engines). Maximum speed 275 km./hr. Cruising speed 235 km./hr. Range, at a total maximum load of 14,700 kg., 5000 km. Description with a reference to armament. *Rev. de l'Armée de l'Air*, March–April, 1939, pages 235–238, 4 illus.

The 746 Km./Hr. of the Heinkel He-112U. H. Rabatel. Predictions made by E. Heinkel in his paper before the Lilienthal Gesellschaft in 1938 are quoted to the effect that the speed record would be broken in 1939. He predicted that progress in engines alone would raise the speed records in the period 1921–1939 from 250 to around 410 km./hr. but progress realized in the fineness would increase them to 700 km./hr. A gain of 60 percent of the speed is due to increase in horsepower, and a gain of 85 percent is due to progress in fineness. Distribution of drag on parts of the Heinkel He-51 biplane of 1931 is compared with that on the He-112 of 1938. Armor for the single-seater cannon fighter is recommended which would permit it to approach the multiseater enemy airplanes and to be invulnerable to their machine guns. Dr. Heinkel is again quoted with reference to the first step toward improving the fineness and Breguet and Devillers are quoted in regard to losses of power due to the radiator. *Les Ailes*, May 4, 1939, pages 7–8, 1 table.

755.110 Kilometers Per Hour! Fritz Wendel, flying a Messerschmitt, lifted the world speed record to 755.110 km./hr., more than 9 km. higher than the record made by Dieterle. Messerschmitt B.F. 113-R airplane was derived from the Me.109 fighter airplane. Engine is the same as that used by Dieterle, a Daimler-Benz D.B. 600 developing in principle 1175 hp. Short note on flight. *Les Ailes*, May 4, 1939, page 5.

GREAT BRITAIN

The Handley Page Hampden. Four-seater bomber (two 1000-hp. Bristol Pegasus XVIII engines) has a maximum speed at 15,500 ft. of 265 m.p.h. At a maximum permissible flying weight of 21,000 lb. it cruises at 212 m.p.h. and at that speed has a range of 1725 miles with a service load of 3587 lb. By reducing cruising speed to the most economical figure of 172 m.p.h. range with the same load can be increased to 1990 miles. Four guns are carried, position of the various gunner's stations being illustrated in a photograph. One cutaway drawing shows location of armament and other equipment on the plane, and a second shows construction. Very long description including design, armament, characteristics and performance, illustrated with photographs and drawings showing components and their assembly. *Aeroplane*, May 3, 1939, pages 569–574, 17 illus.

British Commercial Aircraft. Guide to performance and passenger accommodations of British commercial aircraft produced by Airspeed, Armstrong-Whitworth, Avro, Cunliffe-Owen, De Havilland, Fairey, General Aircraft, Mayo, Percival, Pobjoy, and Short companies. Characteristics and performances are also given for the Short 14/38 landplane (275 m.p.h. cruising speed at 25,000 ft.). *Flight*, April 27, 1939, pages 415–420, 19 illus., 15 tables.

British Transport Aeroplanes. Photographs and specifications of British airplanes in service on the World's Air Lines and also available in the export market. Performance, load-carrying ability and construction of each machine are given in proper alphabetical sequence. The 18 different types described cover all requirements, from the small six-passenger feeder-line airplane to the big intercontinental landplane and flying-boat. Figures for the Short 14/38 A and 14/38 B landplanes included. *Aeroplane*, May 3, 1939, pages 563–568, 11 illus.

For Service Training. New Reid and Sigrist twin-engined three-seater trainer appears to have no vicious tendencies. There is no dropping of a wing near the stall, the controls are light and well harmonized, and machine is reported to be difficult to keep in a spin, and to tend to pull out of it automatically. In slow rolls there seems to be no appreciable loss of height. In addition to affording twin-engined training for pilots, it is equipped for training crews in bombing, navigation, night flying, and in the handling of rear defensive guns. Two De Havilland Gipsy Six II 205 hp. engines are carefully faired into the wing, and a fixed spatted undercarriage is used. With a normal category gross weight of 4900 lb., cruising speed 190 m.p.h. at 2100 r.p.m. at 6000 ft. For aerobatic flying, maximum gross weight 4100 lb. Stalling speed with slotted flaps down 20°, 57 m.p.h. Initial rate of climb 1330 ft./min. Long description with drawings showing "boat-built" construction. *Flight*, May 11, 1939, pages 476c–476e, 14 illus. *Aeroplane*, May 10, 1939, pages 593–595, 9 illus.

Spitfires on Parade. Interception demonstration given at Duxford, by two squadrons of Supermarine Spitfire eight-gun single-seater fighters is described. Sqn. Ldr. H. I. Cozens gave an individual demonstration of the handiness of the Spitfire, despite its exceptionally high top speed of 362 m.p.h., and the limits imposed on the fully supercharged Merlin near the ground. Take-off is obviously handicapped by the fixed-pitch propeller, but is vastly improved by the variable-pitch type. Service pilots usually bring the Spitfire in for a landing at about 85 m.p.h., touchdown speed being at least 15 m.p.h. lower. *Flight*, May 11, 1939, pages 478–479, 3 illus. *Aeroplane*, May 10, 1939, page 591, 1 illus.

Blackburn Aircraft. Development and achievements of the Blackburn Aircraft Company and details of its famous aircraft from the Blackburn monoplane of 1910 to the Skua of today. Second article deals with another chapter in the Blackburn history, taking up the Cirrus engine side and describing the new Cirrus Major 150 engine. *Flight*, May 25, 1939, pages 533–544 and 545–548, 60 illus.

The Bristol Beaufort. General reconnaissance torpedo-bomber twin-engined midwing monoplane of fully stressed-skin construction is of entirely new design and was designed for rapid production with a view to spreading the construction by a considerable subdivision of components. Tail wheel retracting with main undercarriage, hydraulically-operated flaps and mass-balanced ailerons are important features. Very large numbers of Beauforts have been ordered direct from the Bristol Company, and it is understood that the machine will be put into production in Australia, the order being large enough to give direct employment to about 4000 Australian workers. Australian-built Beauforts will be supplied to the Home and Commonwealth Governments and are scheduled to meet requirements of the Royal Australian Air Force and of the Far East Command, R.A.F. Brief note. *Flight*, May 25, 1939, page 530, 526, 2 illus.

Bristol Blenheim Twin-Engined Bomber. A very long description of the design, construction and armament of the Bristol Blenheim and of the long-nosed Blenheim, with performances which have been quoted from this magazine in the British magazines as being quite different from British released data. *Rev. de l'Armée de l'Air*, January–February, 1939, pages 99–109, 13 illus.

The Cunliffe-Owen Flying Wing. Flying Wing with an airfoil-shaped body. By elimination of the fuselage, its skin friction and form drags are replaced by the skin friction and form drags of the tail booms, which are

estimated as considerably less than the drag of the expanded center section. By carrying all the payload in an expanded portion of the wing, design is simplified and much weight saved. About one-quarter of the total weight of the Flying Wing is lifted by the expanded center section. Expanded center section and tail booms are said to be much easier to build than the normal oval fuselage. Airplane is the first to have the new civil-rated Bristol Perseus XIVc sleeve-valve engines of 900 hp. and German V.D.M. fully-controllable and feathering constant-speed electrically-operated propellers. Maximum speed 225 m.p.h. at sea level and 235 m.p.h. at 6000 ft. Cruising speed 195 m.p.h. at 5000 ft. Stalling speed 67 m.p.h. Initial climb 1250 ft./min. Service ceiling 20,000 ft. Range in still air 1950 miles. Disposable load 9500 lb. Payload 4000 lb. Wing loading 23.00 lb./sq. ft. Long description of design, structure and equipment, and cutaway drawing showing location of equipment. *Aeroplane*, May 17, 1939, 625–628, 4 illus., 1 table.

The Equipment of the Royal Air Force. Something like 75 different types of airplane or different versions of standard airplanes are in service with the Royal Air Force. Some squadrons recently equipped with new types are now being re-equipped with even newer types. Construction, engine, armament, and purpose of 50 recent airplanes are given, and a one-page table is devoted to dimensions, weights, and performance with a full load for 75 of these aircraft, including: 5 fighters, 5 Army-Cooperation, 2 general-purpose, 4 single-engined bombers, 14 two-engined bombers, 2 bomber-transports, 6 general-reconnaissance, 1 torpedo bomber, 3 target towers, 1 target, 12 trainers, 10 communications, and (for the Fleet Air Arm) 3 fighters, 1 fighter-reconnaissance, 2 fighter dive-bombers, 1 light reconnaissance, 1 spotter-reconnaissance, and 2 T.S.R. aircraft. Photographs of 40 aircraft are included. *Aeroplane*, May 24, 1939, pages 665–666, 662–664, 40 illus., 1 table.

R.A.F. Fighters and Bombers Since 1918. Historical review of different types of fighters and bombers including war types, single-seater fighters, two-seater fighters, single-engined bombers, medium bombers, and heavy bombers. Tables show single-engined comparisons, and comparative performances of single-seater fighters and heavy bombers 1918 to 1939, and of single-seater fighters and medium bombers. Graph indicates increase in maximum speeds of fighters and bombers of the R.A.F. and of the World's speed records. *Aeroplane*, May 24, 1939, pages 667–669, 1 illus., 3 tables.

A Spartan Demonstration. Demonstration of the Westland Lysander II two-seater Army-Cooperation monoplane with No. 2 (A.C.) Squadron as the demonstrating medium. Squadron now has its full complement of Lysander IIs, which differ from the Mark I mainly in the use of the 905-hp. Perseus XII sleeve-valve engine in place of the 890-hp. Mercury XII poppet-valve motor. These two motors are not interchangeable, as the Perseus mounting has been modified to allow the essential motor-driven accessories, such as the electric generator, air compressor, and vacuum pump, to be driven from a gearbox attached to the air-frame. This gearbox remains in place when motor is removed, thus making complete motor replacement easier. Description of demonstration. *Aeroplane*, May 10, 1939, pages 591–592, 2 illus.

Standard Aircraft of the R.A.F. Forty-two aircraft illustrated are used in large numbers by squadrons of the Royal Air Force, with one or two exceptions. Manufacturers' data are quoted briefly in regard to armament, construction, dimensions, and, in some cases, top speed. *Flight*, May 18, 1939, pages 496–503, 42 illus.

Tipsy Frills. There are four louvre openings in each wing of the Tipsy monoplane, placed to give better flow over the most effective part of the ailerons. These permanent slots, now used in the wing tips of Lockheed 14s, were recently put in the Tipsy two seater, inasmuch as the Tipsy wing was well adapted to take this experimental safety device, and as the Tipsy passes fairly abruptly from aileron control at 36 m.p.h to none at 35 m.p.h, so that effect of slots could be moved easily. Description of performance with and without the slots, and a top view of the airplane showing location of slots on the wings. *Aeroplane*, May 24, 1939, page 683, 1 illus.

HOLLAND

Fokker D.23 Single-Seater Pursuit. D.23 single-seater pursuit monoplane with tricycle landing gear is equipped with two engines arranged in tandem in the fuselage and driving pusher and tractor propellers, respectively the pilot being located between the engines. Armament consists of two Browning-F.N. 7.9-mm. machine guns located in the fuselage and synchronized, and two Browning-F.N. 13.2-mm. machine guns located in the wing and supplied with a Dewandre compressed-air control. Characteristics of these two types of guns are described with specifications and view from above of the installation of the 13.2-mm. Browning gun in the wing of the Fokker 23 is shown. Range of vision from the orthodox single-engined pursuit and that from the Fokker D.23 twin-engine tandem airplane are compared in photographs. Some comments on design and a long description of construction are given. Drum for supplying the Browning 7.9-mm. gun as installed in the side of the Fokker D.23 is illustrated. Two Walter Sagitta I.Sr aircooled 12-cylinder inverted-vee engines each develop 570 hp. maximum. Maximum speed 525 km./hr. at 4100 meters. Climb to 1000 meters in 1 min. 20 sec. Climb to 8000 meters in 16 min. Practical ceiling 3000 meters. Ceiling with only one engine 5500 meters. Range 840 km. at 4100 meters and at a cruising speed of 390 km./hr. *Rev. de l'Armée de l'Air*, January–February, 1939, pages 109–116, 7 illus.

ITALY

Nardi "FN-305" Trainer. Nardi FN-305 is a single-seater low-winged monoplane of mixed construction but can be arranged as a two seater. It is equipped with an Alfa-Romeo 115 185–200-hp. engine and can be armed with either a machine gun firing through the propeller disc, or with two fixed machine guns. Maximum speed with a Fiat A-70 engine 340 km./hr. Climb to 4000 meters 13 min. Range 900 km. Short description, characteristics, and performances with the Alfa-Romeo and Fiat A-70. *L'Aérophile*, March, 1939, page 57, 1 illus.

POLAND

P.Z.L. "Sum" Reconnaissance Airplane. A. Frachet. Three-seater all-metal airplane is armed with six machine guns and can effectively carry out missions of attack and bombardment. With Gnôme-Rhône 14-No-21, maximum speed is 470 km./hr. at 4700 meters and 370 km./hr. near the ground. Long description, characteristics, performance with both the Bristol Pegasus XX (425 km./hr. at 3600 meters) and with the Gnôme-Rhône 14-No-21 engines. *Les Ailes*, April 20, 1939, page 9, 3 illus.

P.Z.L. Mouette Observation Airplane. A. Frachet. Two-seater having total forward and side vision, wood and metal construction, and Handley-Page slots. With one engine (Gnôme-Rhône 14-No. 1 developing 725 hp. at 4440 meters) maximum speed is 360 km./hr. at 3600 meters. Climb to 1000 meters 1 min. 40 sec. to 3500 meters 5 min. 30 sec. Practical ceiling 8500 meters. Long description of construction, characteristics, performances. *Les Ailes*, May 4, 1939, page 9, 3 illus., 1 table.

U. S. A.

The Background of the Barkley-Grow Wing. J. T. Whitaker. Structure of the wing of the Barkley-Grow Model THP-1 eight passenger twin-engined transport airplane is illustrated and briefly discussed. *Aviation*, May, 1939, page 35, 3 illus.

No-Drag Wing Slots. H. L. Hibbard. Lockheed slots which are being put on all Lockheed 14 airplanes, including those already in service, are located directly back of the de-icer boot. Spanwise they extend across approximately 60 percent of the aileron span. They are not continuous, but are installed in five increments on each wing. This arrangement proved fully as effective as a continuous slot in full-scale flight testing. Under normal low angle of attack, high-speed conditions, as at cruising, there is practically no flow of air through the slots and no appreciable reduction in cruising speed. At top speed a speed reduction of about 2 m.p.h. due to use of the slots was measured. Necessity for slots in the case of the Lockheed to prevent stalling is pointed out. *Aviation*, May, 1939, page 32, 2 illus.

Stinson 105. Stinson Model 105 three-seater cabin high-wing semi-cantilever monoplane powered by a 75-hp. Continental engine. Long description, characteristics, and performance. Maximum speed 115 m.p.h. Cruising speed 105 m.p.h. Rate of climb 430 ft./min. Range 420 miles. *Aviation*, May, 1939, pages 28–29, 94, 8 illus.

The Unitwin Vega. M. Short. Unitwin Vega five- to six-passenger monoplane has level landing gear and two Menasco C6S-4 six-cylinder inline air-cooled inverted engines developing 290 hp. each at take-off and linked into a power unit to drive a single propeller. Conventional twin-engined airplane, the Unitwin, and the Douglas DC-3 are compared in regard to airplane drag, wing lift and single-engine control, single-engine performance, noise level in cabin, and weight of powerplant installations. Maximum speed of the Vega Unitwin 210 m.p.h. at 7500 ft. Cruising speed 166–184 m.p.h. for a distance of 570 miles. Long description of the Vega, including equipment, specifications and estimated performance figures. *Aviation*, May, 1939, pages 30–31, 90, 92, 3 illus.

Developing the Erco Airplane. F. E. Weick. Development of the W-1 and W-1A airplanes for the private pilot, and design of the new Erco airplane are discussed in detail. Use of the limited upward elevator travel is continued, and exact manner in which the wings approach the stalled condition has been carefully treated. Problem of avoiding stalling with power on generally entailing additional difficulties in the case of a tractor airplane, was solved by arranging to have the propeller thrust give as large a nosing-down moment as possible. When control wheel is held full back and power is full on, ship does not sink in the usual stall, but will fly in a slow unstalled climb with nose up at an uncomfortably steep attitude. Combination of control and stability is such that plane is in no circumstances likely inadvertently to approach the ground with the nose down. Tricycle landing gear, freedom from stalling and spinning, glide approach to landing, and elimination of rudder control pedals are described. *Aviation*, April, 1939, pages 32–33, 36, 38, 76, 3 illus.

Lockheed Announces 3 New Models; Two Due Next Fall. "Excalibur" is a conventional Lockheed all-metal type of construction still in the drawing-board stage, and will be equipped with four engines and tricycle landing gear. Passenger capacity from 21 to 28 with crew of three. Gross weight 27,500 lb., including 1100 gal. fuel. Top speed 241 m.p.h. Cruising speed 220 m.p.h. Range more than 2100 miles.

Electra 16-E will carry twelve passengers, will weigh 11,500 lb. gross, and will have a span of 60 ft. Lockheed 212 bimotored all-metal all-purpose military plane, delivered to Netherlands East Indies, carries a fixed gun in the nose, flexible gun in the turret with bomb racks under the wing. Few details only. *Western Flying*, May, 1939, page 26.

Lockheed Improves 14. No-drag wing slots installed on the Lockheed Model 14 transports are set immediately aft of the leading edge of the wing and are simple in construction and effective in operation particularly in flying control. There are no movable parts and their design maintains aileron control below normal stalling speeds. There is no interference with de-icer boots and no loss of cruising speed. Drawing and photograph with explanation of operation. *Aero Digest*, May, 1939, page 32, 2 illus.

Martin 162. New Martin twin-motored gull-winged 18-ton flying boat (XPBM-1) for the Navy provides for a crew of seven, with at least three assigned to spherical gun turrets, one in the bow and two amidships on either side of the hull. During rigid water-stability tests and maneuverability tests on water, as well as on take-off and landing, the new boat exhibited the identical characteristics recorded during a series of tests previously conducted by the one-quarter-scale man-carrying flying model. Plane was landed "down" a 21-m.p.h. wind without the slightest porpoise or defect in landing characteristics. Short description. *Aviation*, April, 1939, pages 30–31, 4 illus.

Three-Place Stinson 105 Cabin Monoplane. Wings are provided with slots and flaps, latter being manually-operated. Flaps are fabric-covered steel-tube structures of the trailing-edge slotted type extending inboard from inner edge of ailerons to cabin. They are adjustable to three positions and can be used both for take-offs and landings. Slots are of the fixed inset type and extend over 50 percent of the aileron span to provide increased lateral control at high angles of attack. New 3-place, high wing cabin monoplane is powered with a 75 hp. Continental engine. Maximum speed 115 m.p.h. Cruising speed 105 m.p.h. Cruising range 420 miles. *Aero Digest*, May, 1939, pages 81–82, 6 illus, Short description. *Western Flying*, May, 1939, page 34, 4 illus.

YUGOSLAVIA

Sim—XI. Single-seater acrobatic high-wing monoplane is especially constructed for training in high acrobatics and is equipped with a Bramo-SH 14A 145–160 hp. engine. Maximum speed 200 km./hr. Short description of construction, characteristics, and performance. *L'Aérophile*, March, 1939, page 58, 2 illus.

Aircraft Manufacture

Flying Boats That Bomb. Layout of the Consolidated Aircraft plant, and the major program of maintenance work and new equipment installation recently undertaken. Metal-working methods applied and developed to fit the particular needs of PYB production are described. Toolroom equipment and tooling problems, special setup developed for scarfing or taper work and method of matching faces of the engine mount and those of the oil tank are discussed. *American Machinist*, May 31, 1939, pages 377–386, 21 illus.

Machine Shop at Vultee. D. I. Carroll. To liquidate the heavy machine-tool equipment investment in an aircraft factory, machines must be used nearly 24 hours a day. A number of ingenious fixtures and setups designed by Vultee engineers to accomplish the triple purpose of producing the best possible work, doing it efficiently, and keeping all of the machines busy at all times are described, and various machines used in different operations in aircraft production are discussed. *Aviation*, May, 1939, pages 24–25, 84, 7 illus.

On What We Are Getting for Our Money. C. G. Grey. Series of pictures of the assembly lines of the major British aircraft factories are shown to give an idea of what the aircraft trade are doing to provide the British Empire with an offensive and defensive air force. The author explains how the legend of the smallness of the British aircraft output grew and how the output itself grew in a historical review. Shadow factory and subcontracting schemes are discussed. The peak of the output is nowhere reached. The British Air Ministry has announced that great engineering firms such as English Electric Company and John Brown's, the great steel-making shipbuilding firm and various others of the great industrial undertakings are organized for the building of newer and more powerful and faster airplanes than any of those which appear in this issue. *Aeroplane*, May 17, 1939, pages 620–624, 5 illus., 44 illus. on sup. sheets.

Experimental Production. Editorial comment on the ingenious system of "split" construction, used in the production of the Handley Page Hampden by which the usual bottle neck of production, the installation of equipment, has been avoided; and on the need of a system whereby a relatively small number of "machine-made" versions of the prototype can be got out quickly and sent to the R.A.F. squadrons. Brief. *Flight*, May 4, 1939, page 446.

The Formation of Contoured Sheet Metals by Stretching. Junkers method of stretching sheet metal over wooden formers, used in the manufacture of all-metal airplanes, is described in detail. Cost of formers cannot exceed that of patterns for dies alone for hydraulic presses. Stretching machines are simpler than the usual hydraulic press, and consist essentially of one or more hydraulic rams and suitable hand-operated jaws for gripping the sheet metal. Very irregular work can be formed and, in the case of conical parts, two parts are made at once. Machines, formers, operations, and lubrication of pattern surface are covered with examples of work done. *Engineer*, May 5, 1939, pages 526–527, 5 illus.

Visit to the Henschel Aircraft Factory at Schoenefeld. Points of interest observed during a visit by the German Automobile and Aircraft Technical Society. Henschel Aircraft Company has concentrated on the development of machine tools for machine production of large structural units, and on a method for simple production of required dies for mechanical sheet-metal forming. Drop stamping is carried out on a special machine which enables the two processes of pressing and stamping to be carried out, using elektron dies. For materials of aircraft structures with an aluminum basis, the high-pressure pressing process is extensively applied by substituting a rubber cushion for the die. Due to the large number of single parts in airplane production, the fact that the die can be reused is of decisive importance, and for this reason magnesium alloys are superior to other die materials. Of special interest was the easy operation of the dies by simple compressed-air tools. *A.T.Z.*, April 10, 1939, pages 188–189.

Aircraft Fueling in Air

Fuelling in the Air. C. M. Poulsen. Sir Alan Cobham's system of fueling airplanes in the air is explained in great detail and steps by which the present system was developed are described. One thousand gallons are transferred in less than 15 minutes. The Armstrong Whitworth XXIII being refueled from the Harrow is illustrated and described with many photographs of the equipment used inside the fueling and receiving airplanes. The A.W. XXIII is being used as the receiving aircraft but actually it is used as a flying laboratory and can function alternatively as receiver and tanker. Coupling in the stern is housed in what was the rear gun turret, and hauling cable runs in a tube from center of the coupling toward the winch. *Flight*, May 25, 1939, pages 532a–532d, 9 illus.

Aircraft Performance Testing

Testing Stability and Control of Aeroplanes. A. G. von Baumbauer. Paper and discussion following by L. Bairstow, E. F. Relf, Major C. J. Stewart, N. A. V. Piercy, H. Roxbee Cox, Squadron Leader H. P. Fraser, J. V. Connolly, P. G. Lucas, and Squadron Leader J. F. X. McKenna. (See Aeronautical Reviews, May issue of Journal.) *Journal Royal Aeronautical Soc.*, May, 1939, pages 334–369, 11 illus.

The Testing of Large Aircraft. E. T. Allen, Boeing Aircraft Company. Planning the flight testing of large airplanes, with particular reference to testing of the Boeing 314. Careful choice of the flight crew, and qualifications required of the first pilot, co-pilot, flight engineer, flight recorder, and assistant recorder are discussed. Sample sequence for rehearsal showing the duties of the three primary members of the crew in one maneuver, and a typical flight plan on a test flight of the Boeing Model 314 are given. Tests carried to a marginal point to determine the degree of safety under the most unsafe operating technique and conditions are listed. Problems of analyzing the airplane itself involved in flight testing large aircraft are discussed, and functional systems on the Yankee Clipper are listed. Problems involved in instrument layout and weight control in flight planning are taken up, and performance problems in flight testing are considered. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 12 pages.

Air Transportation

Airline Companies of the World. Details of the airlines operated by 170 concerns, including addresses and flying equipment. *Flight*, April 27, 1939, pages 425–434, 13 illus.

All the World's Air Lines. Name and address, executive head, and chief pilot, territory served, and equipment used are given for all discoverable airline companies. Air traffic in 1938 is shown in a table and air routes of Europe, 1939, are shown on one map, while air routes of the world, 1939, are shown on a three-page map. *Aeroplane*, May 3, 1939, pages 556–562, 4 illus. and map on sup. plate, 1 table.

Commercial Contrasts. Notes on international progress in airline development, including types of airplanes available, tri-motors, and aircraft for high-altitude operation. *Flight*, April 27, 1939, pages 424f–424j, 25 illus.

Equipment for the Airline Operator. Specialized equipment offered by the British industry for airline operation. *Flight*, April 27, 1939, pages 438–442, 8 illus.

"Ex Soton." J. P. Kirton. Procedure at the Empire Base, Southampton, in preparing the Imperial flying boats immediately previous to take-off, and details of the take-off and the flight to and landing at Etang de Berre. *Aeroplane*, May 3, 1939, pages 553–555, 3 illus.

Home Air Lines. N. Tangye. Increase in traffic on internal air routes last year is pointed out in general description of these airlines. *Aeroplane*, May 3, 1939, page 552.

Air Transport across the North Atlantic. R. Boname. Bases for air transport services across the North Atlantic are described, including British bases at Foynes, Shannon airport, Collinstown, Newfoundland (Botwood, Hatties Camp, and Gander Lake), and the continental base at Shediac; American bases at Port Washington, Baltimore, and North Beach, N.Y.; Portugese bases at the Azores and Lisbon; and French bases at Biscarrosse, Bordeau-Merignac, and Saint-Pierre. *L'Aéronautique*, March, 1939, pages 108–117, 24 illus.

Newfoundland Airport. Airport at Hattie's Camp has four runways, three 4500 ft. long and 600 ft. wide, the other 4800 ft. long and 1200 ft. wide. Surfacing consists of 4-in. consolidated Colas premix, laid in two courses and double surfaced. Fog is almost unknown at Hattie's Camp or at Botwood. Description of airport built for transatlantic landplanes. *Aeroplane*, April 26, 1939, page 532.

Recognition of Safety on the Airlines. Colonel E. S. Gorrell. Record of the airlines which, according to the National Safety Council, was 458 percent better in 1938 than it was in 1930 and during winter months was actually 853 percent better. Work of the Council with reference to air transport is discussed. Second article gives the opinions on achieving airline safety as follows: "Philosophy of Operations," R. S. Damon; "Preventive Maintenance," J. F. Martin; "Positive Communications," J. G. Flynn; "Eastern Air Lines Operations," S. L. Shannon; "Maintaining Equipment on E.A.L.," C. Cole; "Engine Overhaul," J. Ray; "Air Transport Communication," D. C. McRae; "Pennsylvania-Central Airlines," F. R. Crawford; "Braniff Airways' Four Maintenance Divisions," R. C. Stunkel; "Handling of Operations on Continental Air Lines," O. R. Haueter; "Continental Air Lines' Maintenance Procedure," P. Briggs; "TWA's Eastern Division," L. G. Fritz; "Engine Maintenance Technique," W. A. Hamilton; "Technical Developments Increasing Airline Safety," W. A. Patterson. *Aero Digest*, May, 1939, pages 50–53, 85–86, 89–90, 93–94, 97–99, 101–102, 105–106, 109–110, 113–114, many illus.

Some Factors Affecting the Cost of Manufacture and Operation of Large Airplanes. A. E. Raymond, Douglas Aircraft Company. It is shown that the large airplane can and does pay, by an analysis of the effect of size on the cost of operating airplanes. The effect of size on the quantity of a model produced is considered and the effect of quantity on the cost per pound of the unit is determined. Variation in cost due to increase in size, other thiugs being equal, is discussed, and the effect of a number of models in a family of similar designs on the cost of the unit as well as the combined effects of all these factors are taken up. Cost of operating an airplane on an airline, and the effect of size on each of these items is examined, including: crew costs, fuel and oil, maintenance, insurance of passenger and equipment, depreciation of the airplane, its propeller and engines, and overhead. *S. A. E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 15 pages, 7 illus.

The World's Airlines 1939. Over 300,000 miles of air routes, covered by the regular services of the World's Air Transport companies, are shown on a four-page map. *Flight*, April 27, 1939, supplementary sheets.

Airports

The Organization of Subterranean Aviation Bases. M. von Roemer. Proposed underground installations designed by a London company specializing in reinforced concrete construction. First base is on the same level as the take-off area and is designed for a coastal region, using sand dunes to camouflage the hangars and annexes. Second base is for a region on the plains where it is not possible to use rolling land and subterranean base is located below the landing and take-off level. Third base is independent of the take-off area, is constructed entirely underground, and comprises hangars and workshops connected to the surface by a well. Foldable-wing aircraft are carried up to and down from the surface by an elevator. Take-off is by means of a catapult located at the opening of the tunnel. Abstract from Deutsche Wehr. March 10, 1938. *Rev. de l'Armée de l'Air*, January–February, 1939, pages 85–88, 3 illus.

Fuel Tanks

To Prevent Burn-ups. Henderson safety fuel tank for a modern two-seater trainer and the same tank after rough treatment are illustrated. In spite of severe deformation tank was still gasoline tight. Walls are sandwiches $^3/_{16}$ in. thick. A layer of "Henconite" is sealed between two layers of metal. The resultant hermetically sealed sheet is very strong but flexible enough to give on impact. Baffles inside the tank are secured to the walls by a self-releasing device so that they become detached in a crash, whereby distribution and pressure of the fuel can equalize itself throughout the tank. No riveting is used. Tank was tested by one of the new type of aircraft cannon firing a 3-in. shell at a 25-yd. range without burst or fire. *Aeroplane*, May 24, 1939, page 684, 1 illus.

Miscellaneous

Designed for Larger Aircraft. Two new series of Fafnir extra-heavy-capacity type bearings, made in ranges adaptable to all modern large airplanes. KH series is single row, DH double row, and KB is designed primarily for torque tube applications requiring bearings with self-contained seals and a high degree of load capacity. Brief reference only. *Aviation*, May, 1939, page 48, 1 illus.

The Standing of the Aeronautical Engineer. A. H. R. Fedden. The status of the aeronautical engineer in England. Abstract Royal Aeronautical Society paper and discussion. *Aeroplane*, May 3, 1939, pages 545–546.

The R.Ae.S. Garden Party. Account of the Royal Aeroneutical Society's annual meeting. First issue deals with the various demonstrations of airplanes in flight, including military as well as civil airplanes. Second issue contains brief description of equipment exhibited at the Static Show. *Flight*, May 18 and 25, 1939, pages 521–524 and 551–553, 20 illus. Account of events with description of both flying and static shows. *Aeroplane*, May 17, 1939, pages 629–632, 29 illus.

Dictators' Air Threats Being Met, National Aero Meeting Told. Account of meeting in Washington, March 16 and 17. and short abstracts of papers presented and discussions following. *S.A.E. Jour.*, April, 1939, pages 9–12, 20–22.

Propellers

Curtiss Reversible Pitch Propeller. Pitch of the new Curtiss electrically-operated propeller described may be reversed to give regular thrust to facilitate ground maneuverability of large aircraft, particularly multi-engined, flying boats. Change to reverse pitch is quickly achieved by the same voltage booster unit used for feathering. Diagram shows maneuverability of flying boat with and without reversible pitch propellers. Few details. *Aero Digest*, May, 1939, page 125, 1 illus. Diagram only. *U.S. Air Services*, May, 1939, page 34, 1 illus.

Ratier Variable-Pitch Propellers of 1939. P. Leglise. Mechanisms and automatic operation of the various types of Ratier variable-pitch propellers, controlled or automatic, are described in very great detail. Means for turning the roots of the blades (links, rack gear, and tangent screws); means for actuating the reduction gear; three-bladed propellers having electric motors and rack gear for the Gnôme-Rhône K-14 engines and having two values of pitch, and feathering; three-bladed propellers having an annular electric motor and rods for engine cannons; three-bladed propellers having an aerodynamic motor (small two-bladed propeller) and rods for engine cannons; propellers having electric motors and rods for the Hispano-Suiza 12-Ydrs; two and three-bladed propellers having electric motor and tangent screws, for Renault 6 Q 220 hp. engines, and three-bladed propeller having an electric motor and control of the blades by tangent screws.

Automatic operation of the r.p.m. by centrifugal force for two pitches; propellers constructed for the Gnôme-Rhône 14-Kfs or Piaggio "Stella" 1X; automatic operation of speed by the aerodynamic reaction for two values of pitch; operation at a fixed point, take-off and climb, and gliding. To be continued. Many drawings. *L'Aéronautique*, March, 1939, pages 91–107, 33 illus.

Vibration Characteristics of Aircraft Engine-Propeller Systems. C. M. Kearns, Hamilton Standard Propellers. Modes of vibration of a complete engine-propeller-mount system are described in regard to modes involving engine-crankshaft torsional oscillations; modes involving engine whirl motions in space, and vibrations involving neither engine-crankshaft torsional oscillation nor engine whirl. Factors influencing resonant frequencies, and aerodynamic damping and internal hysteresis in a propeller, present methods of solving vibration problems, and future trends are discussed. It is estimated that if all vibratory excitations were removed from the propeller, the specific weight could be reduced to approximately 0.20 lb./hp. As an example of this, stress measurements on a propeller operating at 200 percent power and 100 percent speed rating on an electric whirl rig indicated that the stress reached only 15 or 20 percent of allowable alternating value for the particular design. *S. A. E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 21 pages, 15 illus.

The Fairey "Contra" Airscrew. Fairey "contra" propeller consists of two three-bladed fully-feathering constant-speed propellers revolving in opposite directions. Propeller is provided in addition with a preselector arrangement whereby any desired pitch angle may be reached by merely pressing a button. Double propeller is comparatively light, owing to the fact that it has been stressed by the German method. This is possible because of the constant-speed feature which prevents over-revving in a dive. Photograph and very brief note contained in a description of the Royal Aeronautical Society Static Show. *Flight*, May 25, 1939, pages 551–552, 1 illus.

The Manufacture of Metal Airscrew Blades. H. Castaing. Methods used by Hispano Suiza Company in the manufacture of aluminum-alloy propellers (duralumin, alferium, and avional), including: blade blanks supplied; machining from the blank before heat treatment; heat treatment methods; machining the foot of the blade, blade root and blade itself; hand finishing; balancing the blade; and polishing methods. Very long detailed description. Translated from "Revue Technique Hispano-Suiza," October, 1938. *Aircraft Engineering*, May, 1939, pages 211–214, 15 illus.

Rockets

Self-Steering Rockets Use Tiny Gyroscopes. Tiny gyroscopes are now being used to control the direction of rocket flight in experiments at the laboratory of R. Goddard. They are set to apply a controlling force when the long axis of the rocket deviates more than 10° from the vertical. It should be possible, according to Professor Goddard, to apply a compressed air system in the rocket which would be controlled by the gyroscope and which would force the directing vanes out into the slipstream of the rocket and further aid vertical flight. Brief note. *Science News Letter*, May 27 1939, page 329.

Acoustics

The Absorption of Sound by Vibrating Plates Backed with an Air Space. R. Rogers. Rigorous theory presented, after suitable approximations, leads generally to the same results as previous theories. Another theory, intended to be more complete than any previously published, is given for the following purposes: to exhibit the dependence of sound absorptivity on frequency and the various physical characteristics of the material; to show how the physical characteristics may be varied to give a high absorptivity over a band of frequency taken anywhere in the audible range and to show how this band width may be varied; and to present a method for attacking the problem of a vibratory system coupled to a reverberating space. One-dimensional case is treated and results obtained are extended by the present theories of reverberation to a three-dimensional case. *Acoustical Soc. Am., Jour.*, April, 1939, pages 280–287, 4 illus., 1 table, 46 equations.

Estimation of Aeroplane Noise Level. A. W. Morley. Some empirical laws in regard to estimation of airplane noise level, and an account of the present experiments on which they are based. Data analyzed were obtained subjectively, with Barkhausen audiometers, pending standardization of such objective apparatus, and were prone to the inevitable scattering of subjective results which sometimes made analysis difficult. No notice was taken of individual frequency components, but only of their overall effect in producing sensation of noise. Formulas are developed for propeller noise, exhaust noise, and aerodynamic noise arising from the disturbance caused by motion of the structure of the airplane through the air. Problem of combining propeller, exhaust, and aerodynamic noise levels to obtain the resultant level when they act together is discussed. Case of a twin-engined cabin monoplane is considered as an example and loudness level is estimated when the airplane is cruising at 200 m.p.m., 2500-r.p.m. engine speed, with each engine delivering 660 b. hp. *Aircraft Engineering*, May, 1939, pages 187–189, 3 illus., 4 equations.

Reverberation-Time Meter. W. M. Hall. Meter described is so designed that if the reverberating sound in a room decreases in intensity two relays are tripped in succession at different sound levels. Instrument was developed in the Electrical Engineering Department at M.I.T. and its principal merits are simplicity, speed, precision, and portability. Microphone, most of the amplification, and part of the calibrated attenuator between the two relays are provided by General Radio Type 759A sound-level meter, to which two jacks have been added. *Acoustical Soc. Am., Jour.*, April, 1939, pages 302–304, 4 illus.

Aircraft Instruments

The Cobb-Slater Variometer. Variometer consists of a vertical block of transparent material in which two finely tapered holes are bored vertically. Each tube contains a small spherical piston, one green to indicate ascent and other red to indicate descent. Model covers a range of change of altitude up to ±1500 ft./min. Lowest graduation being 50 ft./min. Description. *Aeroplane*, April 26, 1939, page 531.

Stark Position Finder. Position finder may be operated with one hand and eliminates entirely manual plotting of position, locating map position of the airplane on the basis of radio signals picked up by the radio automatic direction finder. Few details. *Aviation*, April, 1939, page 47.

Arens Develops Improved Control. A new spring for use in the casing of tachometer shafts and piano-wire type controls. Few details. *Aero Digest*, May, 1939, page 125, 1 illus.

Miscellaneous Equipment

Way Control Valve. Aircraft Accessories four-way directional control valve operating with very slight pressure, is designed to meet Army Air Corps requirements. Few details. *Aviation*, April, 1939, page 44.

Windshield Wiper. Air Associates electrically-operated rotary windshield wiper has an attachment providing special de-icing fluid. Few details. *Aviation*, April, 1939, page 47.

Aerial Photography and Mapping

Aerial Photography Should Lighten the Load of Army-Cooperation Aviation. A. Charriou. Example taken from the Ethiopian campaign illustrates the extremely important part which modern aerial photography now plays in Army Cooperation. All cartography of the region where the operations were carried on was effected in a very short time which permitted the rapid advance of motorized columns in an unknown country. Author had charge of the mission for the Italian Air Ministry.

A preceding article gives a brief review of papers presented recently at the International Congress of Photogrammetry at Rome. *Les Ailes*, April 20, 1939, pages 11, 8.

Testing Apparatus

Testing Machine for Aeroplane Struts. Avery self-indicating universal testing machine, intended for conducting compression tests on airplane struts having a maximum length of 10 ft., has recently been installed in Short Brothers' aircraft factory. While majority of specimens will be tested to destruction, proof-load tests will be carried out. Tension and transverse testing can also be performed. Machine has a capacity of 50 tons and is particularly suitable for rapid testing. Speed is readily controllable and rate of straining can be made very slow. Machine consists of straining unit, pumping unit and load-indicating cabinet. Oil is employed as the pressure medium. *Engineering*, May 12, 1939, page 577, 1 illus.

Metals

Corrosion and Protective Coatings

Dissimilar Metal Couples. M. R. Whitmore and J. Teres. Investigation to determine effect of dissimilar metal couples on corrosion resistance in salt water, efficiency of various means of insulating such couples, and possibility of predicting corrosion resistance from laboratory measurements of currents and potentials developed by various couples. Aluminum sheet, aluminum-alloy sheet (five types), aluminum-covered aluminum-alloy sheet, naval brass, cadmium-plated naval brass, chromium-molybdenum steel, cadmium-plated Cr-Mo steel, corrosion-resistant steel, monel metal, aluminum rivets, and aluminum-alloy rivets (four types) were tested. Exposure tests on panels made on the Air Corps tidewater rack, reverse bend test, microscopic examination, potentials of dissimilar cells, and current-potential measurements are described in detail. *Industrial and Engineering Chemistry, Ind. Ed.*, May, 1939, pages 608–617, 11 illus., 4 tables. *Heat Treating and Forging*, May, 1939, pages 237–242, 5 tables.

Bright Nickel Plating. O. A. Stocker. Use of brighteners, control and operation, characteristics of the deposit, preparation of base metal, adherence of deposits, ductility of bright nickel, proper anodes, and throwing power of the bath. American Electroplaters' Society paper. *Metal Industry*, May 5, 1939, pages 495–497.

Iron and Steel

Growth of Piston-Ring Cast-Irons. F. Bollenrath and K. Bungardt. Growth of three piston-ring cast irons during prolonged heating at temperatures below 700°C. Irons studied contained approximately, carbon 3.8, silicon 3, manganese 0.8, phosphorus 0.8, chromium 0.1 to 0.5 and molybdenum 0.3 to 0.8 percent. For periods of heating up to 700 hr. the temperature at which growth begins is between 400° and 450°C. At higher temperatures measurable growth occurs only after a time lag which is smaller the higher the temperature. Translated from Stahl und Eisen, No. 41, 1938. *Metal Treatment*, Spring, 1939, pages 21–22, 28, 5 illus., 1 table.

Some General Characteristics of Chromium-Nickel-Iron Alloys as Corrosion-Resisting Materials. F. L. LaQue. Data presented illustrate: effect of nickel in increasing stability of alloys and in supplementing effects of chromium; usefulness of molybdenum in improving corrosion resistance under both oxidizing and reducing conditions and its beneficial effects in connection with specific corrosives; and intergranular corrosion and effects of carbon and stabilizing elements on this phenomenon. *Soc. Motion Picture Engrs., Jour.*, May, 1939, pages 505–517, 1 illus., 5 tables.

Non-Ferrous Alloys

Age-Hardening Magnesium Alloys. W. F. Chubb. First issue—Conditions under which age hardening occurs, and directions indicated for future investigations. Early investigations of aluminum-magnesium alloys; those of Talbot and Norton on 9.6 percent aluminum-magnesium alloy; alloys with aluminum up to 10 percent; metal-working problems; and a brief reference to results of an investigation undertaken at the National Physical Laboratory on properties of aluminum magnesium alloys at elevated temperatures.

Second issue—Binary alloys of magnesium with bismuth and calcium are considered. Both groups exhibit important potentialities. To be continued. *Light Metals*, April and May, 1939, pages 136–140 and 184–186, 5 tables.

The Rolling of Light Alloys. H. Sedlaczek, H. Zapp, and B. Stockbauer. Spread phenomena when rolling various magnesium and aluminum alloys were investigated at the Aachen Technische Hochschule. Material constants for the various alloys were determined which, substituted in the spread formula evolved by H. Sedlaczek gave precise spread values. New factor also permitted excellent comparison of the spread phenomena with steel. Influence of the rolling temperature, composition of material, and speed of rolling upon the spread were also investigated. Description of tests and

results. Translated from Zeitschrift fuer Metallkunde. *Metal Industry*, April 28, 1939, pages 459–461, 9 illus., 1 table.

Ten Years' Service Experience with Alclad Materials in Aircraft. F. C. Pyne. Nature and technical characteristics of Alclad materials are described with particular emphasis placed on the electrolytic processes which, to a great extent, determine the ability of these materials to resist corrosion. Laboratory, weather-exposure, and tidewater-immersion tests, demonstrating outstanding resistance to corrosion of Alclad materials are cited. Tables show: mechanical properties of 0.091-in. thick Alclad sheet after intentional deep scratching of the coating as compared with unscratched material, and available forms, grades, tempers and minimum-specification mechanical properties of Alclad sheet for aircraft construction. *S.A.E. Jour.* (*Trans.*), May, 1939, pages 221–228, 12 illus., 2 tables.

TESTING OF METALS

The Electric Strain Gage. M. A. Rusher and J. W. Matthews. Use of the electric strain gage without amplifiers makes it possible to obtain—even on a switchboard-type instrument—readings of static or low-frequency strains in any member to which the gage head is attached and from these to determine the stresses. A continuous record of the strains can be obtained on a photoelectric recorder if changes are slow or on an oscillograph when variations are more rapid. Various types and their applications are described. *General Electric Rev.*, April, 1939, pages 176–178, 8 illus.

Observing Plastic Deformation with the Microgrid. F. N. Rhines and R. Ward. Microgrid is a very fine grating ruled upon the polished and etched surface of a sample which is subsequently to be deformed. Grid is photographed before and after deformation, thus permitting displacement of any point to be measured by comparison of the photographs. Measurement of changes, etch necessary to reveal location of grains and microconstituents, application of the microgrid method, problem of polyphase alloys, and principal limitations are described. *Metals & Alloys*, April, 1939, pages 129–132, 8 illus.

Spectrographic Analysis and Its Application to Aluminium Alloys. J. R. Handforth, H. W. Whymper, and W. M. Boulton. With the internal standard method considered it is relatively simple to determine whether minor constituents are inside or outside specification limits. Generation of light, and the Hilger, Bausch and Lomb, and Zeiss types of spectrographs, Zeiss microphotometer, Bausch and Lomb density comparator, Hilger microphotometer are illustrated and described. Examination of spectrograms is explained and the logarithmic- and stepped-sector methods are taken up. Spectrographic laboratory of Birmetals, Ltd., and methods for examination of aluminum and magnesium alloys are discussed. *Metal Treatment*, Spring, 1939, pages 3–12, 14 illus., 4 tables.

RIVETING

Riveting Machines and Light-Alloy Rivets. C. Harris. Solid and tubular or semitubular rivets, and the special machines which have been developed for setting them. Tomkins-Johnson high-production-rate Rivetor capable of setting and heading solid rivets at the rate of 140/min., its operation, and controlled setting action; physical considerations to obtain optimum-flow characteristics; various types of tubular rivets; automatic-feed rivet-setting machines produced by the Bifurcated and Tubular Rivet Company with special features. *Light Metals*, April, 1939, pages 133–135, 10 illus.

Paint

The Dope on Paint. H. L. Acker. Development of coatings for use on aircraft with reference to work of the Army and Navy air services in cooperation with some of the larger aircraft manufacturers and aircraft operators; standard finish using zinc chromate primer for all interior surfaces and on exterior surfaces where finish coatings are specified; present accepted finishing system for fabric-covered airplanes; new products that may soon be introduced to serve some peculiar aircraft need, including synthetic organic plastics which are non-drying and non-hydroscopic, formulated in such a way as to produce an ideal sealing compound for integral gasoline tanks, watertightting flying-boat hulls, watertightting the wings, stratosphere sealing, and insulating of dissimilar metals; use of organic plastics; use of synthetic glass suitable for coating polished Alclad airplanes; and a non-film-forming plastic which is non-oxidizing and not in any way affected by high-octane aviation gasoline. Short review. *Western Flying*, May, 1939, pages 15–17, 20, 4 illus.

The Protection of Metal Surfaces against Marine Corrosion and Fouling. E. W. J. Mardles. Painting with most good quality oil paints and enamels under cold and damp conditions was found to produce a film that tends to flake off or blister. Drying time is prolonged two or three fold, especially in the dark. Discussion covers: action of water on paint films; experiences with clear varnishes; proprietary anti-fouling compositions; marine exposure tests at Singapore; toxic pigments for marine work; choice of undercoat; choice of pigment and poison from the standpoint of flow properties of a paint; and application of marine paints under adverse conditions. Contribution from the Royal Aircraft Establishment presented before Institution of Naval Architects. *Engineering*, May 5, 1939, pages 542–544, 3 illus., 1 table.

Engine Design and Research

The Influence of Injection-Timing on the Delay Period in a Compression-Ignition Engine. J. Riffkin. Timing of fuel injection influenced the value of the delay period, and prevailing temperature in the combustion chamber at the instant of fuel injection was probably the major controlling factor. When injection timing was varied from retard to extreme advanced position, delay period at first decreased, passed through a minimum value, and then increased with increasing injection advance timing.

With a high-grade fuel, an injection-advance angle was attained when severe audible "knock" occurred, and further increases in injection advance timings would be accompanied by equal increases in delay period. With high-grade fuel the Tangye engine could be started by hand from cold and operated steadily with an injection advance timing appreciably beyond the point at which severe audible knock occurred. Existence of a second zone of operation would appear to be governed by ignition quality of fuel. Results obtained in additional investigations carried out at the University of Birmingham, test procedure and apparatus. *Engineering*, May 12, 1939, pages 552–553, 4 illus.

Power Loss Accompanying Detonation. N. MacCoull. As the compression was raised above critical compression ratio, it was found that: power output increased steadily with compression ratio if spark advance was adjusted for maximum power at each ratio, limit being set by preignition; if spark was retarded to threshold of the knock at each compression ratio, power increased and then dropped off rapidly at higher compressions; temperature of spark plug, piston and intake valve rose with compression ratio even when free from detonation, but compression ratios above the critical did not cause excessive temperatures; and temperatures of exhaust gas and exhaust valve, and heat losses to jacket were lowered with increased compression ratio, even during detonation, when spark was set for maximum power.

Results of tests on several motor cars and on a single-cylinder C.F.R. engine. Piston temperatures were taken by the method described in Air Corps Technical Report No. 2825, June 25, 1927. *S.A.E. Jour.* (*Trans.*), April, 1939, pages 154–160, 15 illus.

Some Aspects of Engine Wear. H. H. Jackson. Examples of wear of engine parts caused by abrasion, seizure and corrosion as opposed to effects of impact are illustrated and discussed, and various methods of protecting engine parts from the effects of wear are evaluated. Advantages and limitations of the stelliting process, surface hardening, problems connected with design and manufacture of bearings, and future trends are considered. Following developments are mentioned as capable of wider commercial application: local hardening processes already in use in England, Germany, U.S.A. and elsewhere receiving experimental consideration; aluminium base antifriction bearing alloys receiving attention particularly in Germany, where light metal bearings containing hard particles of alumides or 0.1 percent carbon as graphite are in the course of development; and a metal-sprayed bearing which retains a supply of lubricant; and locally heat-treated engine components as having distinct advantages over carburizing. *Aircraft Engineering*, May, 1939, pages 190–193, 19 illus.

Stacks and Rings. G. F. Titterton. Design to provide for expansion and contraction of individual parts as well as the whole exhaust system, due to many rapid changes in temperature from below 0° to 1500°F. Design of an exhaust collector to permit proper servicing of engine, easy replacement of sections of exhaust collector ring, and freedom from structural failure, and weights and materials available for the design of exhaust collectors (S.A.E. 1025 mild carbon steel, 18–8 corrosion and heat-resisting steel, and Inconel) are discussed. *Aviation*, May, 1939, pages 26–27, 86, 88, 92, 7 illus.

Cooling Fuel Nozzles. J. J. Breeze and J. O. Hines. Formation of carbon deposits on the tips of spray nozzles in Diesel engines can be prevented, or at least greatly retarded, by proper cooling of the nozzle. Fuel is used for cooling and rate at which it is circulated varies between 5 and 10 times the rate of fuel consumption under full load. In order to avoid carbon formation at the edges, the tip of the injector should project about 1/8 in. into the combustion chamber. Total amount of heat to be abstracted is small so it is not necessary to have a special cooler, only equipment necessary being a 10-gal. circulating tank, a filter and a suitable gear pump. Authors are with the Royal Dutch Shell Petroleum Laboratories in which the development work was carried out. It is possible to make a cooled injector that is interchangeable with the conventional type. Very brief abstract. Diesel Engine Users Association paper. *Automotive Industries*, May 1, 1939, page 564.

Dynamic Suspension—A Method of Aircraft-Engine Mounting. K. A. Browne. Distinguishing feature of dynamic suspension is named as the accomplishment of a true c.g. support by means of directional spring attachments on the rear of the engine. Data presented include: descriptions of several experimental applications; a chart of spring characteristics for the most useful design; corrections to the basic frequencies for aircraft operation; ground and flight tests on the test stand and dynamometer; and a comparison of an example engine-mount analysis with experimental results. Dynamic suspension mounts built for the Cyclone engines are described and illustrated. Natural-frequency calculations, aircraft structure effect, propeller gyroscopic effect, effect of c.g. overhang, reduction-gear torsional effect, fore-and-aft elasticity, placement of natural frequencies, and motion of the engine are described. *S.A.E. Jour.* (*Trans.*), May, 1939, pages 185–192, 13 illus., 15 equations.

High Output Aircraft Engines. E. W. Hives and F. L. Smith, Rolls-Royce, Ltd. Aspects of the problem of increasing performance of the power plant, both by increasing propeller output and reducing installation losses. Limitations to engine performance are discussed in regard to detonation, effects of supercharger efficiency and intercooling on engine output, and introduction of water into the charge. Few of the mechanical problems which are limiting performance, and the way in which they are being tackled at Rolls Royce are described including bearings, exhaust valves and sleeve valves, failures due to cyclical temperature variations in the engine and thermostatic control of coolant temperature.

Installation development for increased performance is considered which includes pressure cooling of engines and ejector-type exhaust manifolds, with reference to the ejector-type exhaust system patented by Rolls Royce. In the latter exhaust gases are discharged rearwards at high velocity through restricted outlets. Their kinetic energy is utilized to give a propulsive effect which actually adds to the airplane's speed. Advantages of the interchangeability scheme from a national and aircraft constructor's point of view are also discussed. Arrangement of streamline exhaust manifold is illustrated in a drawing. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 33 pages, 18 illus., 3 tables.

Stacks and Rings. G. F. Titterton. Design and installation of aircraft-engine exhaust manifolds and their accessories. Cross-sectional area of collector for rapid discharge of exhaust gases without creating back pressure is discussed. Location of exhaust outlet in regard to fire hazard, carbon monoxide, obstruction of vision, and noise are considered. Exhaust manifolds for Pratt & Whitney Twin Wasp and Wasp, Jr., Wright Cyclone R-1820-G5 and Cyclone R-100-F engines are illustrated and described. Table gives size, area, horsepower capacity and weight per 100 in. for S.A.E. 1025, 18–8 and Inconel exhaust tubing. *Aviation*, April, 1939, pages 28–29, 79–80, 4 illus., 1 table.

The Wear of Crankshafts with "Lead-Bronze" Bearings. C. G. Williams and H. Ludicke, Institution of Automobile Engineers. Relative wearing properties of various crankshaft materials when running against a typical copper-lead alloy, at a bearing temperature of 212°F. were determined in the tests described. Tests were carried out with nickel-chrome-steel crankpins and results suggested that variations in composition of the copper-lead bearings do not have a marked effect on the wear obtained. Plain carbon and alloy steels, three cast materials, and chromium-plated and case-hardened crankpins were tested. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 20 pages, 20 illus., 2 tables.

Engine, Fuel and Lubricant Testing

D.V.L. Thermoelement. H. Berg. D.V.L. thermal element described was developed especially for measurement of average combustion-chamber and exhaust temperatures in internal-combustion engines, and is also suitable for similar methods to measure other temperatures such as cooling means and lubricating materials. By suitable selection of the dimensions, an advantageous and sufficient carrying off of the heat from the welded seam to the socket is provided. This is of importance for the prevention of explosion due to the thermal elements extending into the combustion chamber. *A.T.Z.*, April 10, 1939, pages 198–199, 6 illus.

Spark Timing—Its Relation to Road Octane Number and Performance. L. E. Hebl and T. B. Rendel. Measurements in the author's laboratory have shown that differences between power obtained with present spark timings and that which could be obtained at maximum power spark timing do not differ greatly among automobiles, and are of the order of 1 to 2 percent. Manner in which shape and slope of the highest useful spark-advance curve are influenced by fuel characteristics, engine design, and operating conditions was investigated and a method by which it can be fitted to the maximum-power spark-advance curve is recommended. Effect of spark timing on power and economy, limitations on full-throttle advance, distributor mechanisms, octane number for maximum power, effect of gasoline type on power loss, other conditions using different fuels, and effects of atmospheric temperature and compression ratio are considered. Discussions by E. Bartholomew, J. T. Fitzsimmons, and J. O. Eisinger are given. *S.A.E. Jour. (Trans.)*, May, 1939, pages 210–220, 17 illus., 5 tables.

Test Methods and Test Apparatus for Crankshafts of High-Speed Internal-Combustion Engines. Dr. Cornelius. Test apparatus for investigation of torsional fatigue strength of full-size single or double throws, and of full-size original crankshafts with and without average stress are described. Method of determining the natural torsional vibration number and vibrational form of the power plant is considered including determination of the torsional elastic properties of crankshafts by means of static and dynamic tests.

Method for finding critical r.p.m., size of resonance deflections, and additional stresses on crankshafts due to torsional vibration is discussed, including the indicating appliances and torsiograph. Determination of the reliability of the crankshaft under the operating conditions is taken up. Determination of the bending elastic curve, bending suspension characteristic curve, natural bending vibration number, and the bending fatigue strength of crankshafts is considered. Results of investigation to give the constructor a basis for proper design and calculation of power plants having high piston speeds. *A.T.Z.*, April 10, 1939, pages 190–197, 30 illus.

The C.F.R. Shrouded Intake Valve. N. MacCoull, The Texas Company. From evidence given on effect of changes in turbulence caused by turning the C.F.R. shrouded valve, appreciable differences evidently result in compression ratio for audible knock, heat losses from combustion, either with or without detonation, sensitivity of the thermal plug or bouncing pin as detonation indicators, and cyclic variations. Turning the valve may also cause important differences in antiknock ratings of fuel. One cause of the experimental work reported was to learn if the reason for loss of sensitivity of the thermal plug was due to a shifting of the zone of detonation away from the thermal plug location, by the change in turbulence. Plug was used for some time by the U.S. Army Air Corps for rating aviation fuels and was satisfactory in the C.F.R. engine before introduction of the shrouded valve. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 12 pages, 10 illus.

Engine Fuel Testing and Proposals for Its Further Development. A. V. Philippovich, Director, Institute for Fuel Research, D.V.L. Octane number is adapted to the mean value of road-knock values, and correlation of results with a single-cylinder engine is therefore only of a fortuitous nature. To this are added the disadvantages of its method of determination (bouncing pin, and measurement at a single fuel-air ratio).

For a period of transition at least, author proposes: to retain the Motor method; to determine octane numbers at 30°C. (86°F.), 50°C. (122°F.), and 100°C. (212°F.) mixture temperature under otherwise similar conditions; to record, in each determination, compression ratio prevailing at point of incipient detonation; to introduce an improved instrument for knock indication, which will give accurate and reproducible values; to specify, in appraising fuels for a given engine, (according to its temperature characteristics), the temperature corresponding with octane number requirement or incipient knockpoint; and to investigate octane number in the range of lean mixture ratios. In testing aircraft-engine fuels various laboratories already have succeeded in obtaining diagrams characteristic of knock behavior through determination of obtainable power against intake air temperature, excess air, or fuel consumption. Measuremens of this type appear to be most suitable for fuel rating. For testing of engine lubricating oils on basis of their ring sticking tendency it seems advisable also to have a test procedure which measures the time required for ring sticking under exactly specified conditions over a range of temperatures.

Defects in octane-number determination and faults in its use are discussed in great detail with proposals for improvement in measurement of octane number and for better characterization of engines based on their operating conditions. Change to another fundamental fuel characteristic is considered. Type of present lubricating-oil testing is taken up with proposals for improvement. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 15 pages, 5 illus., 2 tables.

Underwood Oxidation Test and Its Correlation with Service. H. C. Mougey, General Motors Corp. An oil can be tested to determine whether or not it will oxidize, and, if it does oxidize, what products, acid, and sludge will be formed and in what amounts. Amount of inhibitor in an oil can be determined by adding measured amounts of a catalyst, and how much catalyst is necessary to neutralize the inhibitor in the oil can be found. This determination of the amount of inhibitor in the oil measures the total amount of inhibitor but it does not distinguish between inhibitor derived from crude oil and inhibitor added to the oil. Oxidation characteristics of the oil without inhibitor can be determined by adding enough catalyst to counteract the effect of the inhibitor in the oil and then oxidizing the oil. This test indicates the character and amount of oxidation products which may be expected when the oil is oxidized in the engine under conditions where the inhibitor is not effective, for example, on the cylinder walls or in the combustion chamber.

These results are shown in the data given as a result of the Underwood test. By making engine runs under controlled conditions, and by making tests on the road under service conditions and determining what loads, speeds and temperatures are typical of different types of service, it is possible to learn under what conditions the following are important: oxidation in the crankcase, decomposition of sludge on hot surfaces, decomposition of oil in the combustion chamber, contamination of oil in the crankcase, and formation of "varnish" on the piston surfaces and on crankcase parts. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 20 pages, 5 illus., 9 tables.

Laboratory Tests as a Means of Evaluating Performance of Lubricants. F. L. Miller, J. F. Kunc, Jr., and R. W. Richardson, Standard Oil Development Co. Progress made in the development of laboratory test techniques for evaluating motor-oil quality is pointed out, and accomplishments in the work on different phases of the following problems are reviewed: oil consumption and ease of starting; combustion-chamber carbon formation; tendency of motor oils to form sludge; piston-ring sticking; varnish formation; bearing corrosion; and wear characteristics. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 45 pages, 17 illus., 17 tables.

A New Laboratory Method for Rating Aviation Fuels of High Octane Number. R. Stansfield and H. B. Taylor. British and some Continental work has been influenced largely by results of single-cylinder aero-engine tests under rich mixture conditions, while American developments appear to be directed more by full-scale engine tests in which temperature rise of suitably placed thermocouples is assumed to be the criterion of failure, although preignition and other factors have also received attention. Development work leading to the method suggested is based on the two premises that any fuel must exceed a definite minimum antiknock value appropriate for its class when used under lean mixture cruising conditions, and that it must exceed a second minimum when used under rich conditions appropriate for take-off, the two minima not necessarily being the same in terms of reference fuels adopted. Only data from a full-scale British designed aero engine of large cylinder capacity is considered, but there does not seem to be any valid reason why more than minor modifications should be needed to give correlation for other important aero-engine types *S.A.E. Preprint or World Automotive Engineering Congress*, May–June, 1939, 7 pages, 5 illus.

RCA Research Laboratories. Electrically-operated engine indicator diagram equipment, perfected by the RCA research laboratories for accurate and dependable measurement of rapidly changing cylinder pressures. Apparatus is composed of a pressure unit, cathode-ray oscillograph, amplifier and synchronizer unit. Pressure unit is unaffected by temperatures up to 350°C., is built to withstand pressures to 5000 lb., and converts rapidly changing pressures into electrical impulses which are amplified and pictured on the screen of the cathode-ray tube. Few details. *Aviation*, May, 1939, page 49, 1 illus.

Surface Defects in Engine Parts. K. Kornfeld. Effect of surface finish upon the life of an aircraft engine according to a Polish engineer's views. Photographs of defects obtained by different methods of testing—electromagnetic examination, deep etching—are illustrated to bring out the importance of close examination of photographs in order to avoid drawing wrong conclusions from them. In some instances test itself may cause what is apparently a defect in the part, although in fact damage was due to a too vigorous application of the test. Two processes described as necessary to arrive at a correct decision are qualitative inspection consisting in defining the origin of the defect, and utilization evaluation stating what the possibilities are of using a given defective part or of bringing it up to standard, or rejecting it. Examples of defects are analyzed, each in two photographs, one showing appearance of the defect whan magnified two-fold and the other illustrating the microscopic view of the defect. *Aircraft Engineering*, May, 1939, pages 194–198, 200, 36 illus.

Engine Manufacture

Engines for the Air Force. The layout of the Pratt & Whitney Aircraft Company plant for straight-line production of aircraft engines; inspection applied to raw materials and finished parts purchased from the outside; inspection during production; and production test procedure for the engine *American Machinist*, May 31, 1939, pages 369–376, 18 illus.

Multi-Tooling for Aero-Engine Production. Typical series of multi-tooling operations in the production of an aero-engine cylinder barrel are described. Maxicut lathes of Drummond Brothers, Ltd., being used. Tooling for finishing the fin and radius at the root; operations in machining of variable-pitch propeller shafts; turning a crankshaft forging in a lathe; turning the camshafts for inline engines; and production of radial type aero-engine crankshafts. *Aircraft Engineering*, May, 1939, pages 217–219, 6 illus.

Engines

60 Hp. Franklin. New Franklin Model 4AC-171 aircraft engine develops 60 hp. at 2350 r.p.m. and 42.5 hp. at 2100 r.p.m. Bore 3 7/8 in. Stroke 3 5/8 in. Piston displacement 171 cu. in. Fuel consumption at rated hp. 0.56 lb./hp-hr. Weight 159 lb. Description, specifications, and power curves. *Aviation*, May, 1939, page 40, 2 illus.

From Mark I to Major 150. Another chapter in Blackburn history, dealing with the Cirrus engine development. New Cirrus Major 150. 4-cylinder inverted inline engine, described in great detail, has been designed for low maintenance costs. Weighing only 325 lb., engine develops 150 hp. at 2450 r.p.m. Contributors to the construction of the Cirrus are listed. *Flight*, May 25, 1939, pages 545–548, 8 illus.

The Gipsy Minor. Better output and specific fuel consumption than official maximum, which are given by the standard Gipsy Minor engines. Very brief note. *Aeroplane*, May 10, 1939, page 608.

The Rolls-Royce Merlin. The 1145-hp. Rolls-Royce Merlin is shown in a cutaway drawing and other drawings illustrate how the steel liners are held into the aluminum-alloy cylinder blocks and the latter to the crankcase, piston details, and how various drives are taken off the crankshaft. Photographs show the two-speed supercharger of the Merlin X and supercharger parts, and other parts of the engine. Construction, cylinders, crankshaft, and camshaft, valve gear, propeller drive, induction system and controls, and lubrication of the Merlin engine, are described in great detail with references in some cases to the Merlin II, and in others to the Merlin X.

Merlin X has completed service type tests with a two-speed supercharger, and gives 1025/1065 hp. for take-off at 2850 r.p.m. with supercharger in low gear, a maximum of 1145 hp. at 5250 ft. at 3000 r.p.m. (low gear) and 1025 hp. at 17,750 ft. at 3000 r.p.m. (high gear). R.M.2S.M. series of the Rolls-Royce Merlins referred to are designed to operate on 100-octane fuel and have a two-speed supercharger (1300 hp. for take-off, maximum power 1145 hp. at 16,750 ft., 1135 hp. available for climb at 15,500 ft.).

Parts of "Some Notes on Modern High Performance Engines," Rolls-Royce booklet, are referred to, considering the armor plating of inline engines. *Aeroplane*, April 26, 1939, pages 519–528, 20 illus.

Building the Lycoming 50. Operations in the production of the Lycoming 50 aircraft engine are illustrated and explained. *Aviation*, April, 1939, pages 26–27, 13 illus.

The Kestrel XXX. Rolls-Royce Kestrel XXX which has been adopted as standard power unit of the Miles Master, is basically the same as the Kestrel V series but incorporates an improved cylinder construction and is suitable for operation with a constant-speed propeller. Engine is derated for climbing and level flight to provide the longer overhaul life required by a training aircraft, rated boost being reduced to +1/2 lb./sq.in. Rated power 550 hp. at 2400 r.p.m. at 11,750 ft. Maximum power 600 hp. at 2750 r.p.m. at 14,250 ft. Power for take-off 720 hp. at +5 lb./sq.in. boost and 2750 r.p.m. Maximum cruising conditions (weak mixture) 414 hp. at 2400 r.p.m. and −1/2 lb. boost. Oil consumption 4–8 pt./hr. Net dry weight 967 lb. Fuel, 87 octane. Short description. *Flight*, May 11, 1939, page 480, 1 illus.

The Medium-Supercharged Taurus. Bristol Taurus II medium-supercharged sleeve-valve 14-cylinder double-row radial aircraft engine measures.

fully cowled, only 47½ in. in diameter and less than 42 in. in length from leading edge to rear of the controllable gills. Engine is particularly suitable for medium-sized high-performance aircraft for work such as army cooperation and for Fleet Air Arm duties. Bore and stroke 5 × 5⅛ in. Capacity 1550 cu. in. Dry weight 1300 lb. Maximum take-off power 1010 b.hp. at 3225 r.p.m. International rated power 860/900 b.hp. at 2800 r.p.m. at 5000 ft. Maximum power for all-out level flight (5 min.) 1065 b.hp. at 3225 r.p.m. at 5000 ft. *Flight*, May 11, 1939, page 477, 1 illus. *Aeroplane*, May 10, 1939, page 608.

Mercedes-Benz DB-600. Four-cycle 12-cylinder vee liquid-cooled aircraft engine. Cylinder capacity 33 liters. Bore 150 mm. Stroke 160 mm. Maximum power 1050 hp. Maximum r.p.m. 2200. Weight empty 545 kg. Compression ratio 1:6.8. Few details and characteristics. *L'Aérophile*, March, 1939, page 62, 2 illus.

A New Two-stroke Aero-Motor. Caunter 60-hp. two-stroke four-cylinder 2.3-liter inverted inline aircooled crankcase-compression engine weighs 120 lb. There are only three moving parts in each cylinder and only about 100 separate parts in the whole engine. Cruising output 50 hp. at 2400 r.p.m. Cruising fuel consumption 0.488 lb./hp.-hr. Description. *Aeroplane*, May 3, 1939, page 578, 1 illus. *Flight*, May 11, 1939, page 474, 1 illus.

Power for the Airlines. Photographs of the De Havilland 205-hp. Gypsy Six Series II, the Gypsy Twelve 410/425-hp., the 16-cylinder 380/395-hp. Naper Rapier, the sleeve-valve Bristol Perseus (900 hp. for take off), the Alvis Leonides 440-hp., the Pobjoy Niagara V 137-hp. and the Armstrong-Siddley Tiger IX aircraft engines, recommended for transport airplanes. *Flight*, April 27, 1939, page 437, 7 illus.

A Ranger at 1.28 lb. per Hp. Ranger SGV-770B-6 inverted-vee 12-cylinder aircooled engine is said to give America the lightest engine of this type in pounds per horsepower in the world and the lightest specific weight of any aircraft engine under 1000 hp. operating on 87-octane fuel. Approved take-off rating 500 hp. on 87-octane fuel up to 1700 ft. Normal rating 420 hp. from sea level to 5700 ft. Fuel consumption at 300 hp. cruising 0.52 lb./b.hp.-hr. Short description, specifications, and comparative figures for the Ranger and six of the new European engines. Lycoming R-680-E 9-cylinder 300-hp. aircraft engine is illustrated. *Aviation*, May, 1939, page 43, 2 illus.

Results Obtained with Junkers Heavy-Oil Engines in the Service of the Deutsche Luft Hansa. Dr. Stuessel. Advantages of the heavy oil engine; short history of the use of the Diesel by the D.L.H.; statistics in service up to 1937; economy of the Diesel engine; and crossing of the Atlantic in 1938 with the Diesel-engined airplanes. *L'Aéronautique*, March, 1939, pages 121–124, 7 illus., 4 tables.

PARTS AND ACCESSORIES

Vibrating Force Starter with Rubber Suspension for Aircraft Engines. F. Broulhiet has now built a centrifugal starter without the damping previously required by friction couplings. He substitutes in place of it a rubber cylinder which absorbs the coupling impact and in the course of the starting process transmits this as useful torque to the crankshaft. Description and drawing. *A.T.Z.*, April 10, 1939, page 201, 2 illus.

British Sparking Plugs for American Motors. Latest K.L.G. type RA-954 integrally screened plug and the 954-RL unscreened plug are illustrated and successful development of a K.L.G. spark plug adapted for American engines are briefly discussed. Pratt & Whitney granted their approval of the RA-954 after specific tests. *Aeroplane*, May 10, 1939, page 608, 1 illus.

Torsional-Vibration Damper for Heavy-Oil Engines. Damper described was designed on principles evolved by E. Thege and built by Aktiebolaget Atlas Diesel, Stockholm. It is said that on account of its small size the damper can be designed for use with any type of engine, large or small, although damper illustrated and described was designed for a 7-cylinder four-stroke engine of 1280 b.hp. having a normal speed of 300 r.p.m. As much as 20,000 oscillations/min. have been taken care of. Inner portion or hub is bolted to the shaft in which torsional vibrations are to be damped, and rim or damping mass is free to move on the hub and brings about actual damping. *Engineering*, May 12, 1939, pages 558–560, 10 illus., equations.

Turbines

Technical Notes. Gas turbine which, supplied with gasoil, has given 100 hp. at 16,400 r.p.m. has been constructed by M. Jendrassik at Budapest. Total efficiency reached 21.2 percent which is not very far from that for modern aircraft engines. The group comprises on a normal axis, a supercharger having ten stages which supplies air at 2 kg. and a turbine with fireproof casing. The supercharger feeds a fixed combustion chamber where injection takes place and ignition of the masut. The gaseous products are expanded in the blades of the turbine, and then exhaust to the exterior by passing in a heat exchanger having a counter current where they heat the air coming from the supercharger. Tests have now been carried on for 200 hr. Very brief note. *Les Ailes*, March 30, 1939, page 9.

Bearings

Studies in Lubrication. F. Morgan and M. Muskat. Experimental variation of the coefficient of friction with the strength of the lubricant source for a complete journal bearing. Experimental results are at least in qualitative agreement with essential features of the theoretical predictions. Monotonic increase of the friction coefficient occurs when the pressure of the lubricant source is increased. All of the curves for various values of source strength approach the Petroff line as an asymptote at high values of the Sommerfield variable. In case the lubricant source is in the loaded portion of the bearing the curves pass through the origin of coordinates and no thin film region exists. At a certain value of the source strength the friction curve is a straight line when the source is in the loaded portion of the bearing. Position of the source of lubricant has been found to have considerable effect upon the practical operation of a journal bearing, particularly at low values of the Sommerfield variable. Experimental apparatus, procedure and results. *Jour. Applied Physics*, May, 1939, pages 327–334, 7 illus., equations.

Fuels and Lubricants

Special Fuels for Airplanes. Pure products suitable for use as aviation fuels are discussed and are listed in a table with their octane number, primary substances, method of production, possibilities of production and advantages and disadvantages. Isopentane, cyclopentane, cyclohexane, isopropyl ether, acetone, isohexane, isoheptane, dimethylhexane, tetramethyloctane, isooctane, toluene, xylene, and ethylbenzene. Abstract from *Revue Pétrolifère*, April, 1938. *Rev. de l'Armée de l'Air*, March–April, 1939, pages 231–234, 1 table.

New Process for the Production of Aviation Gasolines. E. Houdry, W. F. Burt, A. E. Pew, Jr., and W. E. Peters, Jr. Finished Houdry aviation gasoline will be from 76 to 78 A.S.T.M. octane number clear grade, or approximately 87, 90, 92 octane number with 1.8 ml., 3 ml. or 4 ml. tetraethyl lead per gallon, respectively. A typical 100-octane Army-method (96-octane, motor method) blend, actually marketed, consists of about 25 percent iso-octane, 75 per cent Houdry aviation gasoline, and 2.75 ml. of lead. Explanation of the Houdry process for treating petroleum hydrocarbons catalytically. Abstract American Petroleum Institute paper. *Automotive Industries*, May 15, 1939, pages 618, 623, 1 illus., 1 table.

Diesel Fuel Characteristics Influencing Power and Economy. A. J. Blackwood and G. H. Cloud, Standard Oil Development Co. Data obtained on an extended fuel research program and very largely concerning power and fuel economy which are obtained when using fuels differing in their physical and chemical characteristics. Effects of fuel volatility, ignition quality, and fuel viscosity are discussed in detail. Assuming complete combustion, fuel volatility effects the pints per brake horsepower hour only indirectly as it is related to heating value and ignition quality. Most present-day engines have fixed injection timing, and on such engines ignition quality is a major factor in determining volumetric fuel economy in the upper speed ranges. At the lower engine speeds, heating value in terms of b.t.u. per gallon, or as estimated from A.P.I. Gravity, is the most important consideration. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 13 pages, 6 illus.

Aircraft Radio

Radio in Aviation. N. F. S. Hecht. General survey of radio in aviation with special reference to the Royal Air Force. Difficulties in the following designs and how they were overcome are described: design and installation of fairleads for flying boats; trailing aerials for high-speed aircraft; high-tension power supply for the transmitter, low tension for the filaments, and high tension for the receiver; high-tension and grid-bias supply; radio frequencies for fighters and other aircraft required to fly in formation; and vibration effects. Long abstract Institution Electrical Engineers paper. *Engineering*, May 5, 1939, pages 537–538.

Technical Progress in the Art of Instrument Landing. H. W. Roberts. True position of instrument landing today, its present state of development, and forecast of probable trends. Problems of instrument landing and their solutions offered, methods of obtaining a straight-line glide path, and the Air-Track, IT & T Bendix-Airlines and the CAA-Metcalf project are discussed. Problems of the immediate future are mentioned. *Aero Digest*, May, 1939, pages 69–70, 1 illus.

Towards 100 Percent Regularity. F. Brent. First issue—Suggested equipment and methods for airline operation in poor visibility including aircraft flaps, instruments, radio, and self-contained navigation. Author advocates convenient placing of radio operator in relation to pilots, duplication of blind flying instruments, and simplification of other instruments. Instrument-flying panels in the control cabin of the Dornier Do.24 four-engined transatlantic flying boat are illustrated.

Second issue—The technique of blind approach and landing is considered in detail including the "ZZ" method and its variations, a last-minute procedure, ultra-short-wave technique, aural signals, and the possibility of failure of the system. *Flight*, April 27, and May 4, 1939, pages 424a–424d and 461–464, 7 illus.

Aviation Radio. D. Fink. RCA Type 303-A frequency limit monitor suitable for frequency-limit measurements for all classes of transmitters but particularly adaptable to aircraft work. Air Radio 25-lb. 10-watt transmitter and a beacon receiver. Aerovoice portable transmitter and receiver especially useful for small planes such as the Taylor Cub which do not have auxiliary power supply. Fairchild Radio Compass Type C-6 tuning the beacon band only, from 195 to 415 kc. and suitable for visual indication, aural-null indication, or for use as a beacon receiver. Hermes Trans-receiver Type 1050–51 for transoceanic auxiliary service or Imperial Airways planes, consisting of transmitter, receiver and dynamotor power supply housed in a single casing weighing complete 43 lb. Brief descriptions of these devices, and an aerial photograph marked to show the Western Electric intercommunicating radio system used at the Martin Company for safety during test flights. *Aviation*, May, 1939, pages 46–47, 4 illus.

Blind-Approach Systems. A. E. Edis. Suggestions for a blind approach and landing system giving continuous visual information to the pilot. Two directional radio receiving stations are situated equidistant from the airport on a line at right angles to the approach line, and are connected by land line to a transmitting station situated in turn on the approach path produced. Aircraft makes its initial approach by homing on the transmitter station, enters the blind approach sector about 7 miles from the airport approximately along the approach path, and switches on its transmitter. Continuous signals indicating bearing of the aircraft relative to the two directional stations at any instant are radiated from the transmitter station. Signals received by the aircraft are amplified and passed respectively to two milliammeters having long pointers, intersection of which on the map would indicate continuously and exactly the position of the aircraft relative to the field. Accurate information regarding height of aircraft would be provided by three sensitive altimeters connected in the usual way for barometric pressure at the airport. *Flight*, May 25, 1939, page 531, 1 illus.

More about Ice. Weather forecasts for aviation will be in the future include an estimate of the freezing level, according to British Air Ministry orders. Main use of this information is the guidance it gives on ice formation, the danger existing up to about 4000 ft. above freezing level in clouds of the layer type and to 8000 ft. in cumulus. Brief note. *Aeroplane*, May 17, 1939, page 612.

Pilots

The Modifications of the Blood Composition Produced by Alcohol and By Altitude. Abstract from *Revista Medica Peruna*, June, 1938. *Rev. de l'Armée de l'Air*, March–April, 1939, pages 223–224.

Violent Headaches and Nasal-Sinus Colds of the Aviator. Médecin-Commandant A. L. Flamme. Etiology, pathogeny, prophylaxis, and treatment. Discussion of article by Capt. H. G. Armstrong and Dr. Heim entitled "Aero-otitis-media." *Rev. de l'Armée de l'Air*, March–April, 1939, pages 177–186.